Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
Review of the Commission's Rules Governing the 896-901/935-940 MHz Band	)	WT Docket No. 17-200
	)	
Realignment of the 896-901/935-940 MHz Band to Create a Private Enterprise Broadband Allocation	)	RM-11738 (Terminated)
	)	
Amendment of the Commission's Rules to Allow for Specialized Mobile Radio Services Over 900 MHz Business/Industrial Land Transportation Frequencies	)	RM-11755 (Terminated)

To: The Commission

COMMENTS OF PERICLE COMMUNICATIONS COMPANY

These comments are submitted in response to FCC 17-108, Notice of Inquiry, adopted August 4, 2017.

Pericle Communications Company ("Pericle") is a consulting engineering firm specializing in wireless communications. Founded in 1992, Pericle consults for the public safety, personal wireless, transportation, utility and broadcast industries. Through its client, the City and County of Denver, the company was deeply involved in the formulation of the 800 MHz rebanding plan adopted by the Commission in 2004. Pericle continues to help public safety agencies hunt down and resolve 800 MHz interference, including recent work for the City of Oakland, California.

Our firm has considerable experience and depth of knowledge regarding co-existence of narrowband land mobile radio users and broadband cellular base stations. Consequently, pdvWireless, a petitioner in RM-11738, retained Pericle to conduct a study and produce a white paper addressing the technical impacts of subdividing the 900 MHz band into a 2x2 MHz narrowband segment and a 3x3 MHz broadband segment employing the LTE standard. The attached white paper summarizes the results of this study and addresses many of the FCC's questions found in paragraph 40 of the NOI.

In the white paper, we analyze both uplink and downlink interference mechanisms that can potentially affect Part 90 and Part 24 incumbent users. While the FCC does not adopt any specific proposal for realignment in its NOI, we have assumed the Petitioners' proposal for the purpose of assessing technical impacts to incumbent licensees (see RM-11738 comments). Traditionally, the FCC has allocated guard bands between dissimilar wireless services to help prevent interference resulting from the *near/far* problem where a narrowband user is attempting to receive a weak signal from a distant repeater while simultaneously facing interference from strong broadband carrier. But guard bands waste spectrum. Petitioners in the RM-11738 proceeding proposed no guard band, with narrowband users operating immediately adjacent to the 3 MHz broadband segment. One of the key questions is whether narrowband and broadband users can co-exist under this scenario?

To answer this question, three types of potential interference were analyzed:

- Downlink Out-of-Band Emissions (OOBE)
- Uplink OOBE
- Receiver-induced interference (blocking and spectral regrowth)

To understand the effect of out-of-band emissions, we modeled 900 MHz incumbent desired signals from actual sites and broadband LTE interference from a typical network. Three markets were modeled: San Antonio, TX; Orlando, FL and San Diego, CA. For broadband downlink interference, we found that out-of-band emissions resulted in predicted $C/(I+N)$ values less than 17 dB (an established minimum standard, see § 90.672) in a small number of study tiles (less than 1%), in all three markets. Potential uplink interference was predicted to be even more rare, *much* less than 1% of the service area, primarily due to the limited number of simultaneous broadband subscribers under the LTE airlink standard and the fact that LTE subscribers operate with at least 9 dB backoff over 98% of the time.

Another type of potential interference is receiver-induced strong signal interference which typically manifests itself as blocking or spectral regrowth in the receiver's low noise amplifier. The land mobile radio receiver is a complex device with performance that is very much vendor-dependent and the best way to assess receiver performance is to measure it, which we did. These measurements show that typical radios operating in the 900 MHz band perform quite well adjacent to a 3 MHz-wide LTE carrier. In fact, they perform as well without a guard band as some of the best-performing public safety radios when faced with the more familiar broadband interference problem at 800 MHz.

We conclude that a 3 MHz broadband LTE carrier operating from 937 to 940 MHz can co-exist with narrowband Part 90 and Part 24 incumbents. In the rare case of harmful interference, we propose remedies similar to those found in § 90.672 (which also has existing remedies) and § 22.913, including a Power Flux Density (PFD) limit of 3,000 $\mu W/m^2$ to harmonize in part with § 22.913(b).

Other recommendations include methods for limiting OOBE and high power flux densities at ground level, including

- Avoiding siting broadband antennas close to the ground
- Co-locating the broadband cell site with the incumbent when possible
- Employing broadband cell site antennas with suppressed sidelobes
- Installing bandpass cavity filters with greater rejection outside the 3 MHz segment

Respectfully submitted,

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By

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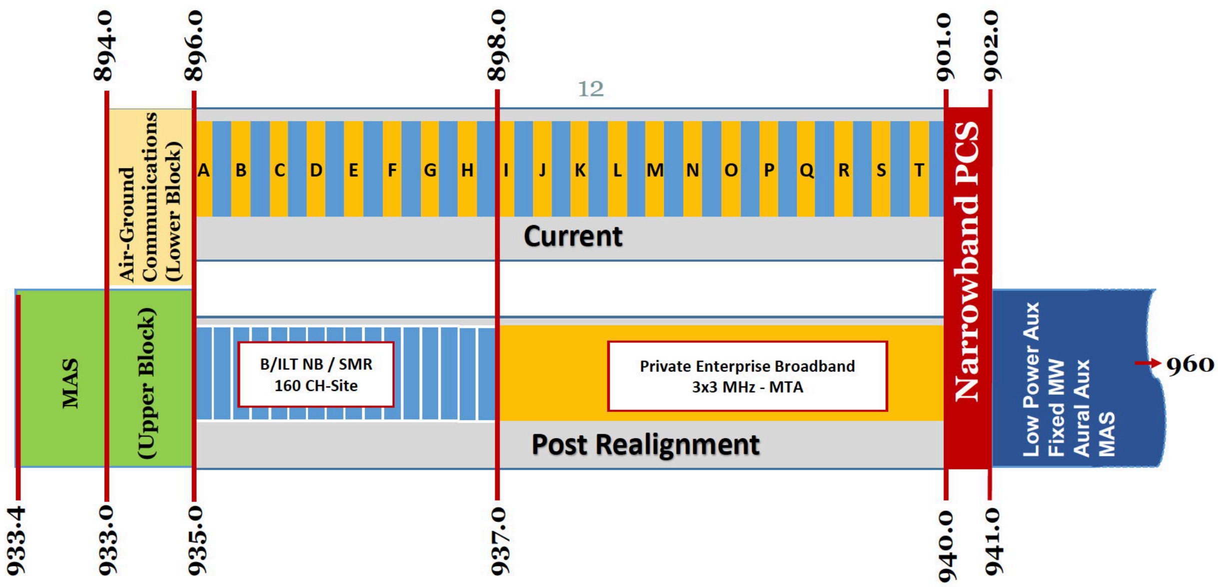
October 2, 2017

Attachment: White Paper, "Technical Impacts of a 900 MHz Private Enterprise Broadband Allocation," September 29, 2017.

Technical Impacts of a 900 MHz Private Enterprise Broadband Allocation



September 29, 2017

Prepared for:

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1.0 Executive Summary

In late 2014, the Enterprise Wireless Alliance (EWA) and Pacific Datavision, Inc. ("pdvWireless") (collectively, "Petitioners") jointly filed a Petition for Rulemaking with the FCC to subdivide the 900 MHz land mobile radio band into narrowband and broadband segments. The Petitioners sought to create a 3x3 MHz broadband wireless service at 900 MHz to support the business enterprise community, especially the critical infrastructure industry (CII), with push-to-talk voice, high speed data and other broadband services [1].

The FCC solicited comments on this petition and numerous comments were filed by interested parties expressing concern about co-existence among incumbent narrowband radio systems and a broadband LTE carrier. On August 4, 2017, the FCC terminated the petition proceeding and adopted a Notice of Inquiry (NOI) to "... begin a proceeding to examine whether any rule changes may be appropriate to increase access to spectrum, improve spectrum efficiency, and expand flexibility in the 896-901/935-940 MHz band (900 MHz band) for next generation technologies and services" [13].

Our firm was asked by pdvWireless to conduct a study aimed at answering questions posed by the FCC in the NOI. This study has three objectives:

- Provide an independent view of the technical impacts of a 900 MHz band realignment
- Create a greater understanding of the technical challenges involved
- Propose methods to mitigate the occurrence of harmful interference should it occur

This white paper specifically seeks to address the questions raised by paragraph 40 of the NOI:

> "40. *Technical rules*. We generally seek comment on whether any changes to the technical rules are necessary to keep pace with changing technology, to ensure that this band is used efficiently, and to prevent interference to in-band or adjacent-band licensees. For example, if the Commission were to create a broadband service in the 900 MHz band, it would need to consider rule changes to avoid interference between a broadband licensee and narrowband licensees in adjacent spectrum segments and possible rule changes to avoid interference to services in adjacent bands. We seek comment on the rules that would be necessary, what physical and technical parameters commenters suggest, and whether those rules and parameters would be sufficient to prevent disruption to low-latency, high-reliability utility operations. We also seek comment on what measures would be appropriate to avoid interference between co-channel broadband licensees. What factors should be considered in developing these technical rules? For example, are the receivers in the adjacent services designed to appropriately filter unwanted emissions?"

In this white paper, we analyze both uplink and downlink interference mechanisms that can potentially affect Part 90 and Part 24 incumbent users.[1] While the FCC does not adopt any specific proposal for realignment in its NOI, we have assumed the Petitioners' proposal for the purpose of assessing technical impacts to incumbent licensees. Most of our conclusions apply generally to broadband/narrowband coexistence at 900 MHz.

We conclude that the potential for harmful OOBE interference from a 900 MHz broadband carrier does exist on both the downlink and uplink paths, but the potential is low and can be further minimized by limiting out-of-band emissions to a $55+10\log_{10}(P)$ dB emission mask (measured in a 30 kHz bandwidth)[2] and by applying good engineering practice tailored to the specific circumstances present in the 900 MHz band and the specific market.

On the downlink path, our modeling and analysis shows harmful interference could possibly occur near the broadband cell site, especially when incumbent downlink signals are weak. But this harmful interference is typically confined to less than 1% of the service area. If additional interference reduction is needed, four mitigation techniques should be considered:

- Do not site broadband antennas close to the ground
- Co-locate the broadband cell site with the incumbent when possible
- Employ broadband cell site sector antennas with suppressed sidelobes
- Install bandpass cavity filters with greater rejection outside the 3 MHz segment

Of these, a 12 dB or 22 dB bandpass cavity filter (rejection at band edge) is the most straightforward approach and might be considered for use at all broadband cell sites for consistency.[3] Similarly, using an antenna with suppressed sidelobes in the elevation pattern could also be considered for all cell sites because it reduces out-of-band emissions at ground level *and* because it reduces the interfering signal amplitude to values below the threshold where blocking or spectral regrowth is likely to occur in the narrowband subscriber unit. Similarly, avoiding unusually low antenna heights also reduces strong signals on the ground.

Our analysis of uplink interference from LTE mobile subscribers shows even fewer cases of potential interference with much less than 1% of the service area could be potentially affected by harmful OOBE. Mitigation of uplink interference is more difficult to achieve than downlink

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[1]In land mobile radio the terms *outbound*, *talk-out* and *inbound*, *talk-in* are also used. In cellular radio, the terms *forward path* and *reverse path* are also used. The LTE base station is called the eNodeB, but we will use the more generic term *base station* for the LTE fixed site and *repeater* for the narrowband incumbent fixed site.

[2] Or equivalently, $50+10\log_{10}(P)$ attenuation in a 100 kHz bandwidth.

[3] See Appendix C for a datasheet from CCI showing a cavity bandpass filter with at least 25 dB rejection at the broadband channel edge.

interference, but the very small percentages of the service area potentially affected by harmful interference indicate that mitigation should rarely, if ever, be required.

Receiver-induced interference (e.g., blocking and spectral regrowth) was measured on the bench for three typical 900 MHz subscriber radios.[4] Strong signal interference rejection was quite good for the three models of radio measured, even at the narrowband channel immediately adjacent to the LTE carrier (936.9875 MHz).

To put this subscriber performance in perspective, it helps to compare it to the 800 MHz interference problem faced by public safety users. Public safety users generally operate from 851 to 860 MHz with three cellular operators operating from 862 to 894 MHz. The nearest is Sprint who operates a nationwide cellular network with a 1.25 MHz-wide CDMA carrier and a 5 MHz-wide LTE carrier between 862 and 869 MHz. The public safety radio is also exposed to strong signals from the A-Band operator who may be transmitting multiple CDMA, UMTS or LTE carriers between 869 and 880 MHz. Frequencies above 880 MHz are typically attenuated by the front end filter in the receiver. Thus, public safety users are faced at times with interference from at least two broadband carriers, but they benefit from a 2 MHz guard band.

To compare the two interference scenarios (900 MHz and 800 MHz), we also measured the same three subscriber radios under the 800 MHz scenario with two broadband interfering carriers. Measurements show that interference rejection at 900 MHz matched or exceeded performance of the emulated 800 MHz case, a situation that is generally considered acceptable provided good performing radios are used (like the ones tested for this study). This is an interesting and far-reaching result because it shows that interference from a single LTE carrier with no guard band is no worse than interference from two broadband carriers with a 2 MHz effective guard band (the 800 MHz case).

It is also important to note that the best performing radios at both 800 MHz and 900 MHz do not employ bandpass filters to reject cellular carrier interference (the most obvious solution) because of practical limitations, but instead employ sophisticated RF Automatic Gain Control (AGC) algorithms to mitigate non-linear effects of strong interfering signals.

There could still be rare occasions when harmful interference occurs. In these cases, there should be remedies for the incumbent and these remedies should be captured in new FCC rules that follow precedents set in rulings for the 800 MHz band [4], [8]. Specifically, these new rules should stipulate the following:

- Incumbents are entitled to remedies if their desired signal is above a threshold such as -98 dBm for mobile units and -95 dBm for portable units.

[4] Blocking and spectral regrowth are defined in Section 3.0 of this white paper.

- For strong signal receiver-induced interference, the incumbent is entitled to remedies if the Power Flux Density (PFD) of the interfering signal exceeds 3,000 $\mu W/m^2$.
- The broadband carrier should notify incumbents in advance of new cell site construction.
- Out-of-band emissions for broadband base stations shall be attenuated by at least $55+10\log_{10}(P)$ dB measured in a 30 kHz bandwidth or $50+10\log_{10}(P)$ dB measured in a 100 kHz bandwidth.

The remainder of this report is organized as follows: Section 2.0 describes the EWA and pdvWireless joint petition which is the only specific proposal for 900 MHz realignment. Section 3.0 explains the types of radio frequency interference that might occur as the result of the 900 MHz realignment. Section 4.0 addresses interference and transmitter combiner impacts on Part 90 narrowband incumbents while Section 5.0 addresses the same issues with Part 24 users. Section 6.0 suggests new FCC Part 90 rules to mitigate any interference that might occur. Section 7.0 concludes the report with a summary of the key findings and recommendations. Appendix A provides coverage and interference maps for three typical markets analyzed for OOBE interference. Appendix B is the test plan for measuring strong signal interference rejection in the subscriber receiver. Appendix C contains manufacturer datasheets for 900 MHz transmitter combiners, cavity filters and 900 MHz broadband base station and subscriber radios. Appendix D derives the relationship between Power Flux Density and power at the antenna terminal.

2.0 The EWA and pdvWireless Petition

Today, the 900 MHz band consists of two 5 MHz sub bands: 935-940 MHz for downlink and 896-901 MHz for uplink, a total of 399 12.5 kHz channel pairs. The Petitioners stated that a realignment of the 900 MHz band presents a rare opportunity to create a broadband service for business enterprise entities, including CII users, some of whom are current licensees in this band [1]. The Petitioners propose a realignment with the following technical characteristics:[5]

- A 3x3 MHz broadband segment at 898-901 MHz and 937-940 MHz
- A 2x2 MHz narrowband segment at 896-898 MHz and 935-937 MHz
- Broadband segment to be assigned to the entity in each MTA holding at least 15 of the 20 wide-area geographic (YD) licenses available. This Private Enterprise Broadband (PEBB) licensee would fund the relocation of existing narrowband licensees in the broadband segment to comparable facilities either in the narrowband segment or elsewhere.
- No guard band, but a stringent out-of-band emission requirement of $55+10\log_{10}(P)$ dB in

[5] Some of these points were not included in the original Petition but were offered by the Petitioners in reply comments.

a 30 kHz bandwidth where *P* is the transmitter power in Watts.[6] This emissions requirement applies to all emissions outside the 3 MHz band segment and applies to both fixed base stations and mobile subscriber stations.
- Fixed base stations in urban and suburban areas would have a maximum ERP as a function of power spectral density with values harmonized with existing 700 MHz and 800 MHz rules for cellular radio.
- Mobile subscriber stations would be limited to 3W ERP and portable stations would be limited to 1W ERP.

The FCC solicited comments on the Petition for Rulemaking via its Public Notice, dated November 26, 2014 [2]. Many of the comments addressed the technical feasibility of the proposed broadband realignment and these comments informed the FCC's questions in the NOI. Because many of these questions concern the potential for harmful interference, we first define the types of radio frequency interference relevant to this situation.

3.0 Types of Potential Interference

Interference between dissimilar services at band edges is a reasonable concern that has been addressed in past proceedings, including 800 MHz rebanding [4]. In the 900 MHz case, there are two types of users at the band (or segment) edges: Part 90 narrowband LMR users and Part 24 Narrowband PCS (NPCS) users. The band relationship is shown in Figure 1.

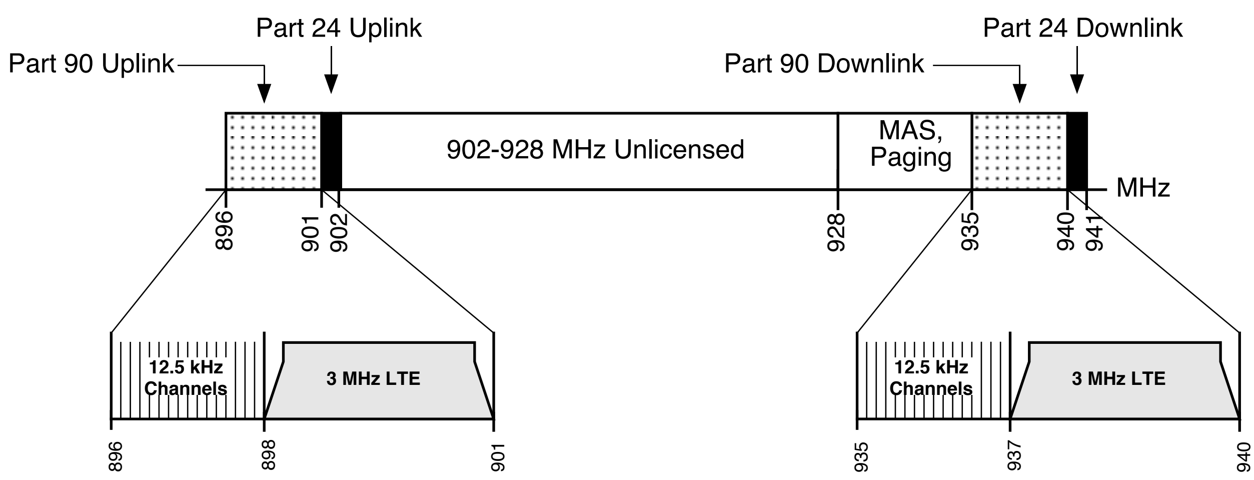

Figure 1 - 900 MHz Band Plan as Proposed by EWA and pdvWireless

[6] Ex Parte Comments of EWA/PDV, Proposed 900 MHz PEBB Allocation Rules, RM-11738 (filed May 3, 2015).

Part 90 subscribers are primarily LMR devices operating through fixed repeater sites while Part 24 users are primarily smart meters also operating through fixed collection sites, although the communications protocol is quite different than push-to-talk radio.

3.1 Types of Broadband Interference

Potential interference from the broadband system falls into several different categories, but all are a consequence of the *near/far problem* where a narrowband user is operating in the immediate vicinity of a broadband base station or a broadband user is operating near a narrowband repeater site. The relevant types of interference are the following:

- Transmitter out-of-band-emissions (OOBE)
- Receiver intermodulation (IM)
- Receiver-induced spectral regrowth
- Receiver blocking (also called receiver *overload*)

Interference can occur either on the *downlink path* (base station to subscriber) or the *uplink path* (subscriber to base station).

For our purposes, transmitter OOBE will be modeled by the Petitioners' proposed emission mask of $55+10\log_{10}(P)$ dB attenuation below the transmitter power in a 30 kHz bandwidth or more simply, -25 dBm in a 30 kHz bandwidth.

The type of receiver intermodulation that is of most concern is *strong signal* receiver IM where the interfering signals range from -50 dBm to -10 dBm. Several of the comments during the petition proceeding compared the 900 MHz realignment to the 800 MHz public safety interference problem. It is helpful to compare and contrast the two situations. Strong signal receiver IM is a serious problem for some 800 MHz public safety radios because they are susceptible to interference from Sprint 800 MHz base stations where a CDMA and an LTE carrier are present and also from cellular A-Band cell sites where multiple broadband carriers are present. Co-located Sprint 800 MHz and cellular A-Band cell sites also introduce IM products between the two wireless providers and this co-location constitutes the worst-case 800 MHz interference situation.

In the 800 MHz band, Sprint deploys a 1.25 MHz-wide CDMA carrier at 862.9 MHz and a 5 MHz-wide LTE carrier at 866.3 MHz. The cellular A-Band operator may deploy a UMTS (3G) carrier, CDMA carrier or LTE carrier above 869 MHz. The potential third-order products in the 800 MHz band (2A-B type) are shown in Figure 2. We see from Figure 2 that some of these IM products span the entire 800 MHz public safety band (851-861 MHz).

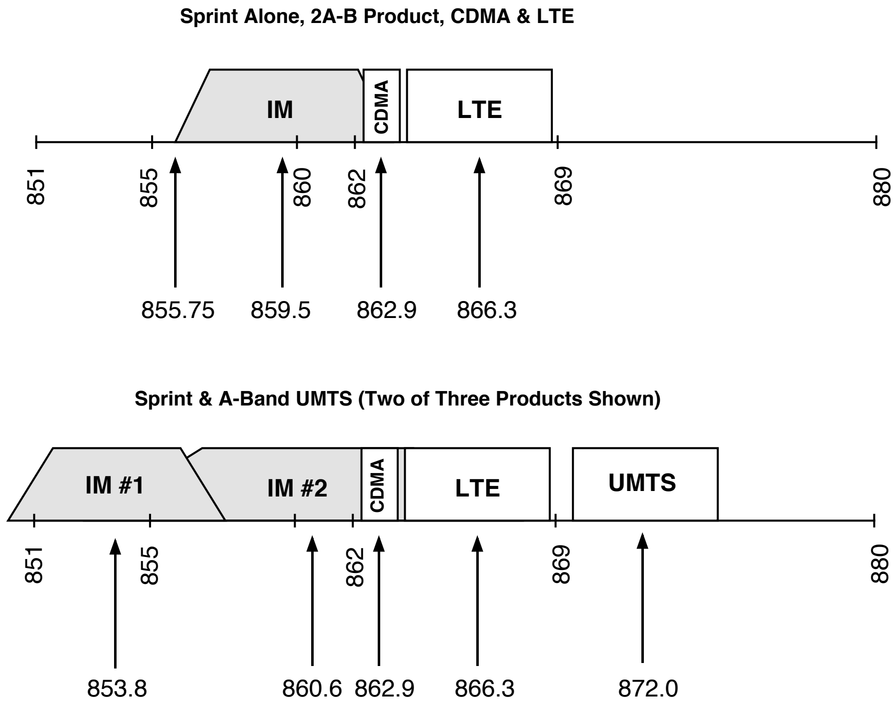

Figure 2 - 800 MHz Cellular 3rd Order Intermodulation Products (amplitude not to scale)[7]

But 900 MHz is different because there is only one proposed broadband carrier close enough to the narrowband 900 MHz users to cause IM and IM requires at least two RF carriers.[8] The only type of two-carrier broadband IM that is likely to occur at 900 MHz are mixes between the LTE carrier and 900 MHz narrowband carriers and only if the two systems are co-located on the same tower (and roughly the same height on the tower) or rooftop. If the two systems *are* co-located there will not be a near/far problem for the subscribers of the co-located narrowband system, only potentially for other 900 MHz users operating near the co-location site and communicating with a distant repeater site. This would seem to be a rare case and one that can be mitigated or simply avoided at the time of deployment.

It is well known that a single strong interferer can cause receiver desense through an effect called *blocking*. Blocking can occur several MHz from the frequency of the desired signal and is usually measured at least +/- 1 MHz from the desired frequency. Another source of desense that

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[7] The third product in the co-location case is A+B-C type, roughly 12.25 MHz wide and centered on 857.2 MHz. In general, the bandwidth of an IM product is a function of the order of the product and is roughly equal to the sum of the products of each interferer's bandwidth and its IM product coefficient (a crude but useful approximation). The power density of these IM products is typically not uniform even if each interferer is uniform (i.e., square) because the convolution of the two signals creates a trapezoidal shape in the frequency domain.

[8] For traditional IM. Spectral regrowth from a single broadband carrier shares many of the characteristics of IM as a consequence of the signal modulation and inherent non-linearities in the amplifier.

generally occurs at closer spacing is *spectral regrowth*. Spectral regrowth is a form of intermodulation that occurs when a modulated signal passes through a non-linearity. Another way to describe it is to recognize that any device that produces intermodulation products in the presence of two (more more) distinct carriers will inevitably produce spectral regrowth due to intermodulation in the presence of a single broadband modulated signal. If a single interferer is relatively close to the desired signal in frequency (i.e., less than +/- 1 MHz), the effect may be less blocking and more spectral regrowth.

There may be situations where the 900 MHz broadband LTE carrier creates strong signals on the street in locations where the incumbent's desired signal is weak. If the receiver cannot fully reject the unwanted signal, some receiver impairment will occur due to blocking and spectral regrowth in the receiver front end. All land mobile radios are subject to strong signal interference at one time or another, so the potential for harmful interference does not in itself preclude co-existence with a broadband LTE carrier. In fact, 800 MHz public safety users face similar strong signals every day and most modern 800 MHz radios can reject this type of interference sufficiently that performance is only rarely impaired. One measure of the impact of receiver-induced interference at 900 MHz is whether it is worse than 800 MHz interference to public safety users, a situation that is generally considered acceptable if good performing subscriber radios are used.

Like public safety 800 MHz receivers, narrowband 900 MHz receivers are better equipped to deal with a single strong interferer (blocking) than IM products of two interferers. Typically, receivers can withstand signals as high as -25 dBm before blocking occurs (as measured by the TIA-603-D method or similar).[9] That said, the lack of a guard band at 900 MHz may potentially introduce desense that does not occur at 800 MHz, due to spectral regrowth in the receiver LNA.

To summarize, at 900 MHz there is a single broadband interferer and no guard band while at 800 MHz there are two or more broadband interferers and a 2 MHz guard band.[10]

3.2 <u>The Broadband LTE Radio Carrier</u>

The Petitioners proposed to allow deployment of 4G broadband facilities employing the 3GPP LTE standard waveform. The LTE standard supports several different bandwidths, including 1.4, 3, 5, 10, 15 and 20 MHz. The Petitioners propose a 3 MHz-wide LTE carrier which has a

[9] Based on this firm's bench measurements of 800 MHz and 900 MHz subscriber radios.

[10] For most public safety users. During rebanding, some 800 MHz public safety licensees elected to retain their frequencies in the 860-861 MHz expansion band and their guard band is only 1 MHz.

maximum occupied bandwidth of 2.7 MHz.[11] The LTE downlink carrier employs Orthogonal Frequency Division Multiple Access (OFDMA) and Orthogonal Frequency Division Multiplexing (OFDM). OFDM splits the LTE carrier into many subcarriers, each 15 kHz wide. Each subcarrier can operate with QPSK, 16-QAM or 64-QAM modulation, depending on the instantaneous carrier-to-noise ratio (*C/N*). On the uplink, LTE employs a pre-coded version of OFDM called Single Channel, Frequency Division Multiple Access (SC-FDMA). SC-FDMA has a lower peak-to-average power ratio than the downlink modulation which results in lower battery consumption.

LTE has a time-slotting characteristic similar to Time Division Multiple Access (TDMA) using 10 ms long frames with 10 subframes and each subframe having two slots of 0.5 ms each.

A resource block (RB) is the smallest unit of frequency and time that can be allocated to a user. The resource block is 180 kHz wide in frequency and 1 slot (0.5 ms) long in time. In frequency, resource blocks are 12 x 15 kHz subcarriers wide.

The 3 MHz LTE downlink carrier can support gross data rates as high as 15.1 Mbps with no antenna diversity or 60.5 Mbps with 4x4 MIMO.

LTE is normally deployed as an N=1 reuse scheme meaning that all sites and all sectors operate with the same radio frequency carrier. Self-interference is managed using time sharing of the channel and path loss which attenuates self-interference between the co-channel cell sites.

Subscribers share the LTE channel on a slot-by-slot basis and only one subscriber transmits in its assigned frequency segment (one or more 180 kHz-wide resource blocks) at a time. While only one broadband subscriber is transmitting in a resource block in a sector at one time, the interference present at the 900 MHz narrowband repeater is the cumulative interference from all broadband subscribers with signals above the noise floor of the narrowband receiver.[12] Further complicating the modeling problem is that the LTE subscriber radio uses power control that is a function of its distance from the LTE base station, not its distance from the affected repeater.

On the downlink, the amount of LTE OOBE power captured by the narrowband receiver depends on several factors:

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[11] The maximum occupied bandwidth is equal to the maximum number of resource blocks multiplied by the bandwidth of a resource block (180 kHz). For a 3 MHz LTE carrier, the maximum number of resource blocks is 15 and the maximum occupied bandwidth is 15 x 180 kHz = 2.7 MHz.

[12] To be more precise, a signal exactly equal to the thermal noise floor of the receiver increases the effective noise floor by 3 dB. From the point of view of the victim receiver, it is preferable that the interference be below the thermal noise floor by some amount that would make the interference impact negligible, say 1 dB. For a 1 dB impact, the interference must be 6 dB below thermal noise ($10\log_{10}(1 + 0.25) = 1.0$ dB).

- The path loss from the LTE base station to the narrowband subscriber radio
- The LTE base station vertical antenna pattern
- The emission mask which is $55+10\log_{10}(P)$ dB in a 30 kHz bandwidth
- The equivalent noise bandwidth of the narrowband receiver

Because the emission mask requirement is relative to transmit power, the maximum allowed emission is -55 dBW or -25 dBm, independent of transmitter power. This simplifies the modeling and the analysis. Narrowband receivers designed to operate on 12.5 kHz channels (2.5 kHz max deviation for analog FM) require an equivalent noise bandwidth of 5.5 kHz for FM and P25 and 7.0 kHz for DMR [5]. In practice, manufacturers must employ wider IF bandwidths to accommodate frequency stability errors at both the base station and the subscriber unit. The additional bandwidth required can be calculated if the frequency stability of each transmitter and receiver is known [5]. To accommodate these frequency errors, manufacturers typically widen the IF bandwidth to 8.5 kHz (equivalent noise bandwidth) for 12.5 kHz channels. Because the emission mask is measured in 30 kHz, the actual power captured in the receiver's IF bandwidth is $10\log_{10}(8.5/30)$ or -5.5 dB relative to the power in 30 kHz.[13]

3.3 Potential 900 MHz Interference

Incumbent users who might be adversely affected by a 900 MHz broadband carrier fall into two categories: Part 90 narrowband users and Part 24 users. Part 90 narrowband devices are generally push-to-talk radios and the band segment edges under the Petitioners' proposal would be 898 and 937 MHz. Part 24 users at the band edges (901 and 940 MHz) are primarily Advanced Metering Infrastructure (AMI) devices for utilities, otherwise known as smart meters. The potential for interference to these two types of incumbent users is addressed in the next two sections.

4.0 Potential Interference to Part 90 Incumbents

According to the Petitioner's proposal, the PEBB licensee is obligated to provide comparable facilities following band realignment and we expect that obligation to include no loss in ERP. During the petition proceeding, commenters expressed concern that realignment will require tighter frequency spacing and therefore greater combiner loss. There are several ways to address combiner loss if it occurs: lower-loss combiners, higher gain antenna, greater transmit power, lower loss coaxial cable, or as a last resort, an additional transmit antenna (to achieve wider channel spacing in the combiner).

[13] Assuming the out-of-band emissions approximate white noise over 30 kHz.

In contrast, FCC precedent does not require a relocating party to guarantee the absence of interference or even no greater interference than the *status quo*. Instead the FCC has traditionally followed a policy of limiting out-of-band emissions and ignoring receiver performance. Recent decisions by the FCC put more burden on the receiver without mandating specific receiver performance. In the case of 800 MHz rebanding, the FCC adopted new rules establishing minimum performance standards for victim receivers to be entitled to protection, a minimum $C/(I+N)$ the victim receiver is entitled to, and a procedure for reporting and correcting interference when it occurs [4]. More recently, the FCC created a *harm claim threshold* of interference power flux density (PFD) above which the victim licensee is entitled to protection [6]. Thus, the FCC is now placing some of interference mitigation burden on the receiver by establishing a threshold below which the receiver is expected to function. Above this threshold, the burden is on the transmitter. For the purpose of this white paper, we are not proposing a standard for comparable facilities with respect to broadband interference, rather we seek to understand and quantify potential interference and devise practical methods to reduce any actual interference to manageable levels.

As stated in Section 3.0 of this report, there are four types of interference under consideration:

- Transmitter out-of-band-emissions (OOBE)
- Receiver intermodulation (IM)
- Receiver-induced spectral regrowth
- Receiver blocking (also called receiver *overload*)

Transmitter and receiver-induced interference and transmitter combiner issues are treated separately in the following subsections. The first two subsections address the interference issue for two cases: Part 90 downlink interference at the 937 MHz segment edge and Part 90 uplink interference at the 898 MHz segment edge. The third subsection addresses the transmitter combiner concern raised by incumbents and the fourth subsection addresses downlink receiver-induced interference.

4.1 Part 90 Downlink OOBE Interference

On the broadband carrier downlink, OOBE might affect Part 90 subscriber receivers by creating a higher noise floor within the intermediate frequency (IF) bandwidth of the receiver. The Petitioners have proposed an emissions limit below 937 MHz of no greater than $55+10\log_{10}(P)$ dB below the transmit power, measured in a 30 kHz bandwidth. It is straightforward to show that this limitation is equivalent to no greater than -25 dBm in a 30 kHz bandwidth, independent of transmitter power. Most Part 90 narrowband users are limited to $43+10\log_{10}(P)$ dB which is equivalent to -13 dBm (see §90.210, emission mask I). Additional bandpass filtering can be used at the broadband base station to reduce the -25 dBm even further, if necessary. For this study, we modeled carrier-to-interference plus thermal noise ratio, $C/(I+N)$, for the -25 dBm case and for -37 dBm and -57 dBm to represent additional filter rejection of 12 and 22 dB, respectively.

Today, Bittium offers both LTE base stations and subscriber units that meet the -25 dBm out-of-band emissions standard. Datasheets for Bittium radios are found in Appendix C.

To understand the effects of downlink OOBE, we picked three typical markets to model with the goal of identifying those areas where the *C/(I+N)* of the incumbent due to OOBE is below 17 dB.[14] These three markets are San Antonio, TX; Orlando, FL and San Diego, CA. The propagation software used was **EDX SignalPro™** with 30 meter terrain data and the National Land Cover Database (NLCD). The propagation model was the TSB-88.2-E Anderson 2-D diffraction model with clutter loss. This model is an industry standard and is widely accepted for land mobile radio. Broadband OOBE was modeled as a co-channel emitter of -25 dBm in a 30 kHz bandwidth or -30.5 dBm in 8.5 kHz bandwidth (the IF bandwidth of the incumbent subscriber unit). Incumbent interference from all incumbent repeaters was modeled at -13 dBm -5.5 = -18.5 dBm. The actual incumbent site data and ERP were used from the ULS, assuming a typical 10 dBd gain antenna (dbSpectra Model DS9A10F36U3D).

The useable signal threshold for the incumbent subscriber was assumed to be -101 dBm on a fading channel which corresponds to a 12 dB SINAD static sensitivity of -120 dBm and a Delivered Audio Quality (DAQ) of 3.4 [4].

The broadband cell site antenna height was set at 36.6 meters (120') and the study area was arbitrarily set to a 15 mile radius. A 60 meter tile size was used for this study.

We are interested in the case where the *C/(I+N)* in a study tile is less than 17 dB and the broadband OOBE is stronger than the cumulative incumbent OOBE *and* the incumbent signal is greater than -101 dBm. **EDX SignalPro™** signal amplitude data was exported to **ESRI Arcview™**to perform this analysis and produce coverage maps for each market.

An actual typical incumbent network was selected in each of the three markets for modeling the desired signal.

Figure 3 shows the *C/(I+N)* results for San Antonio for the incumbent Lower Colorado River Authority (LCRA), a regional utility. The tiles in red correspond to *C/(I+N)* < 17 dB. They comprise 0.65% of the tiles in the 15-mile service area and are limited to a few hundred meters around each broadband cell site.

Figure 4 shows the *C/(I+N)* results for Orlando, FL for the incumbent Duke Energy. In this case, the red tiles correspond to 0.041% of the service area.

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[14] The minimum *C/I+N* set by the FCC for 900 MHz B/ILT. See FCC § 90.672(a)(1)(ii)(B).

Figure 5 shows the *C/(I+N)* results for San Diego for the incumbent San Diego Gas & Electric (SDG&E, a subsidiary of SEMPRA). Here, the red tiles correspond to 0.11% of the service area. For San Diego, we have co-located three of the six LTE cell sites with incumbent SDG&E repeater sites. Note the absence of red tiles (indicating $C/I+N$ < 17 dB) around the co-located sites.

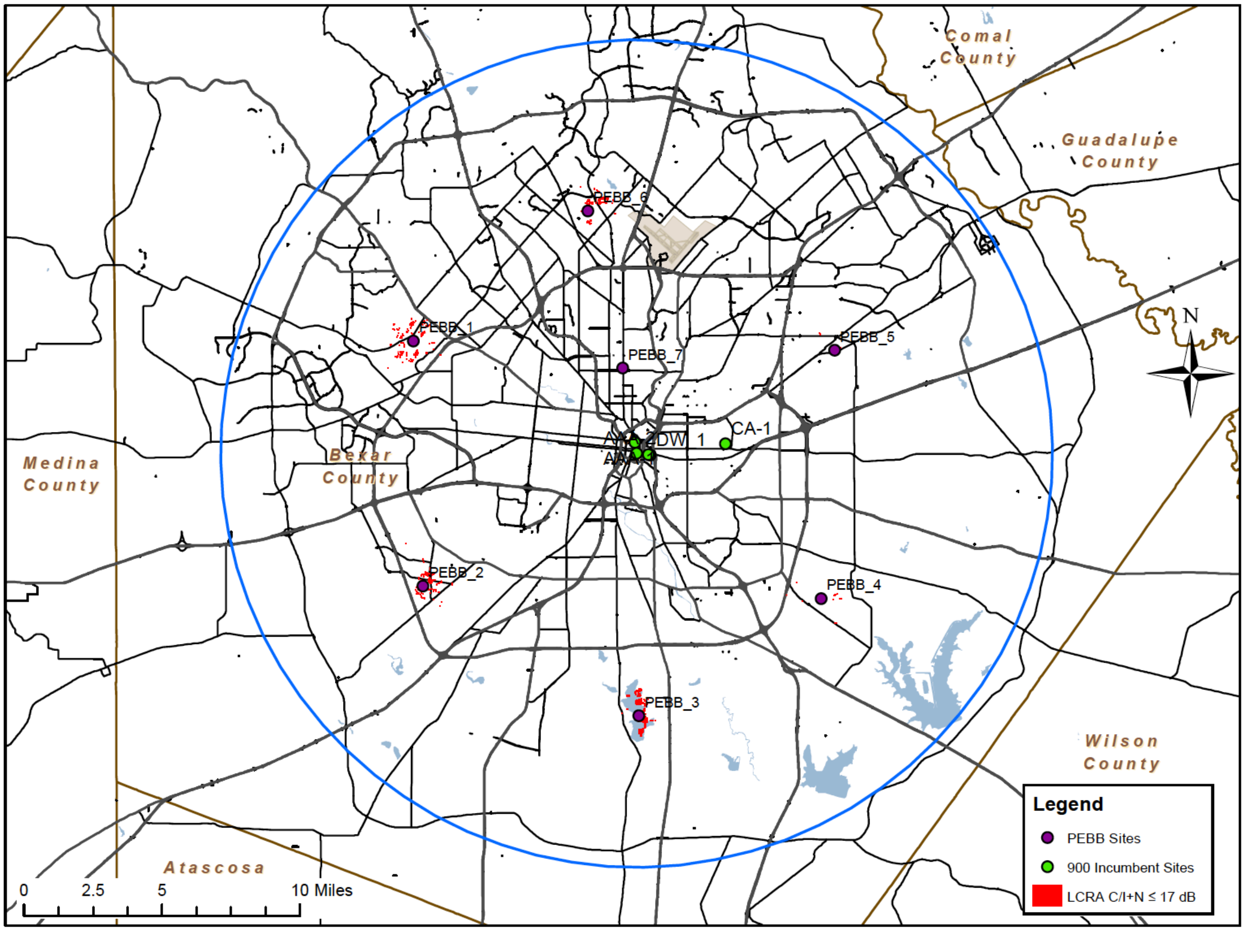

Figure 3 - Downlink OOBE Impact from 7-Site Broadband Network in San Antonio (LCRA)

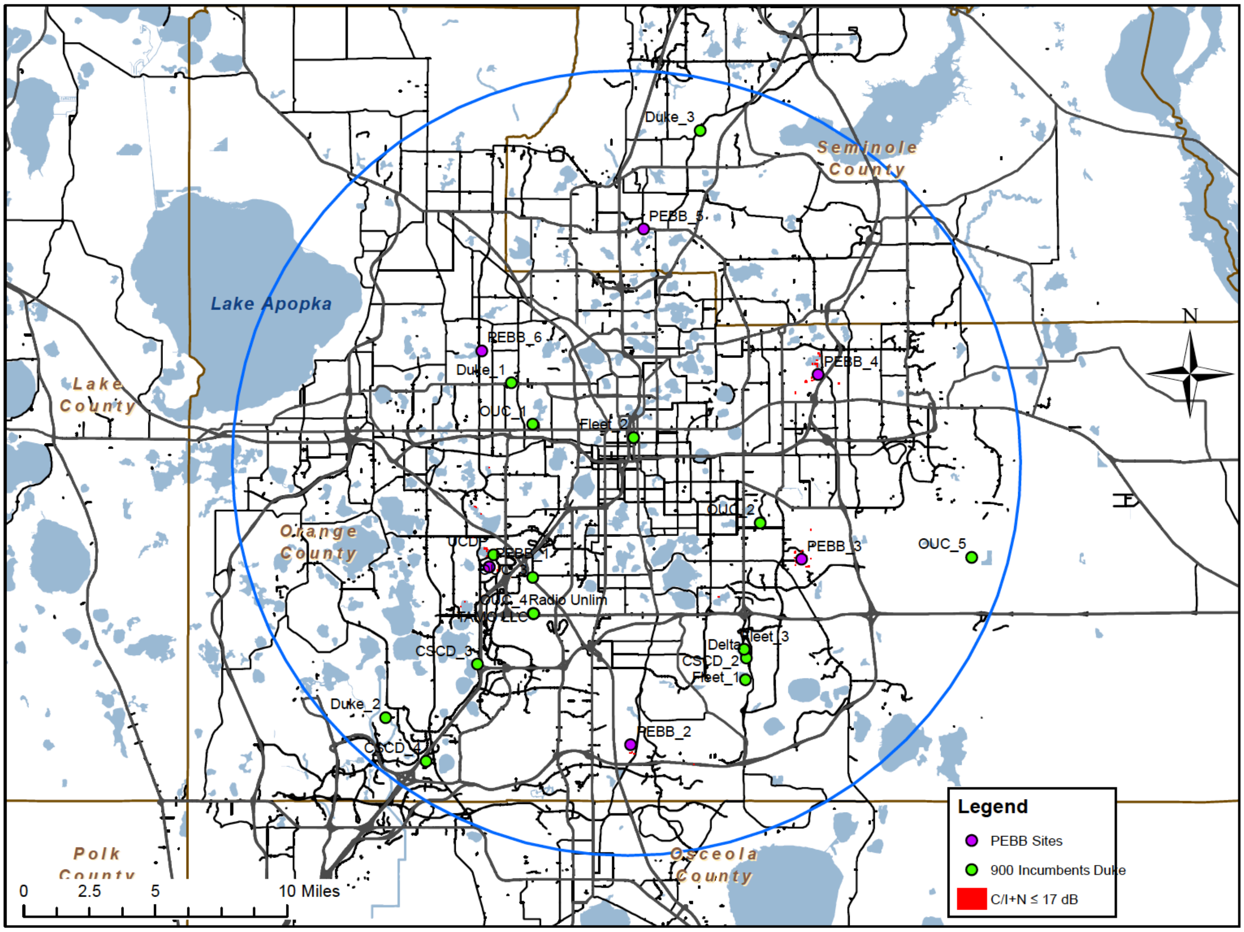

Figure 4 - Downlink OOBE Impact from 6-Site Broadband Network in Orlando (Duke Energy)

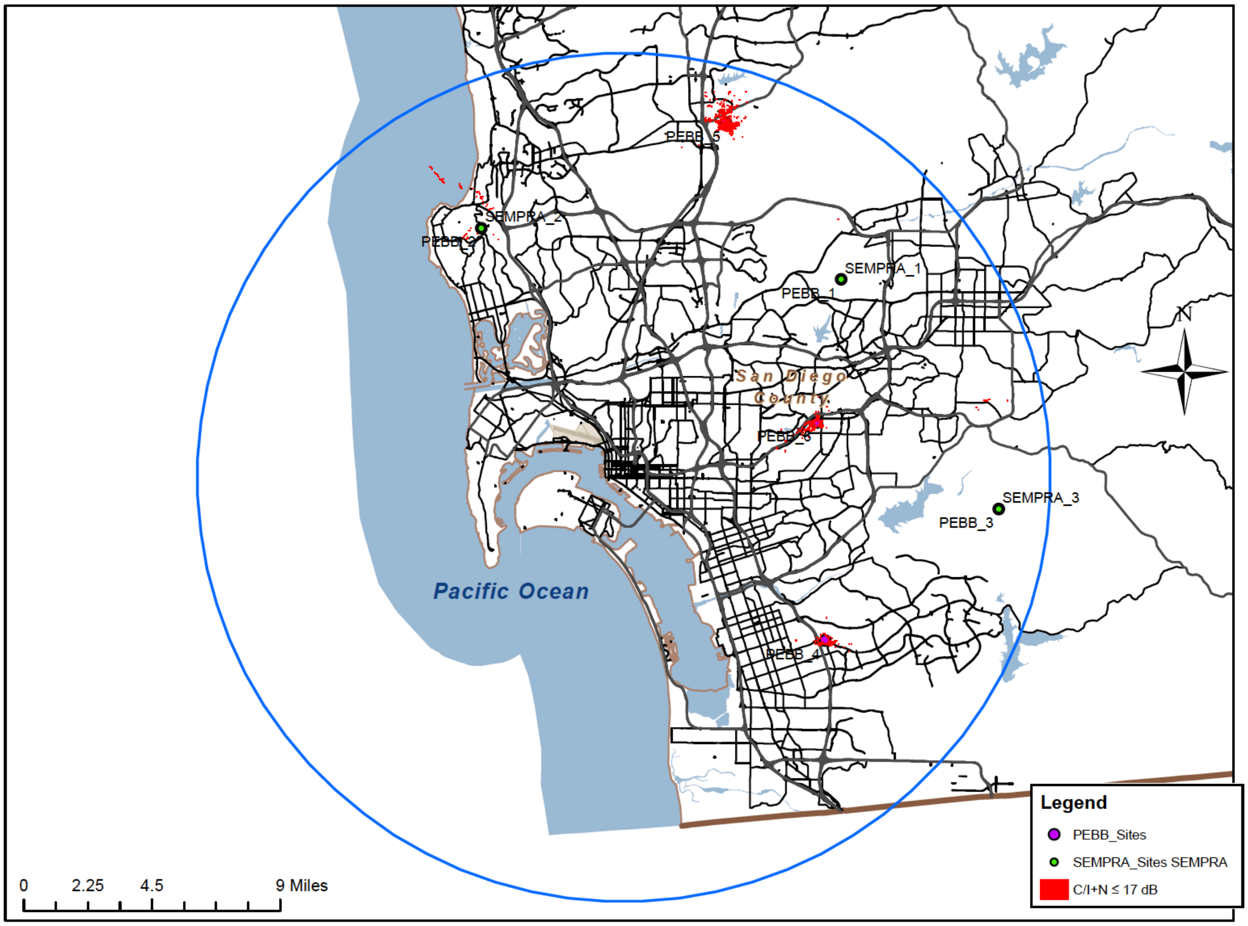

Figure 5 - Downlink OOBE Impact from 6-Site Broadband Network in San Diego (SDG&E)

If interference should occur, base station filters can reduce the impact considerably as shown in Figures 6 and 7 for a 12 dB and 22 dB filter, respectively, in the San Diego market. The 12 dB filter reduces the tiles with *C/(I+N)* less than 17 dB to 0.023% and the 22 dB filter to 0.0013%.

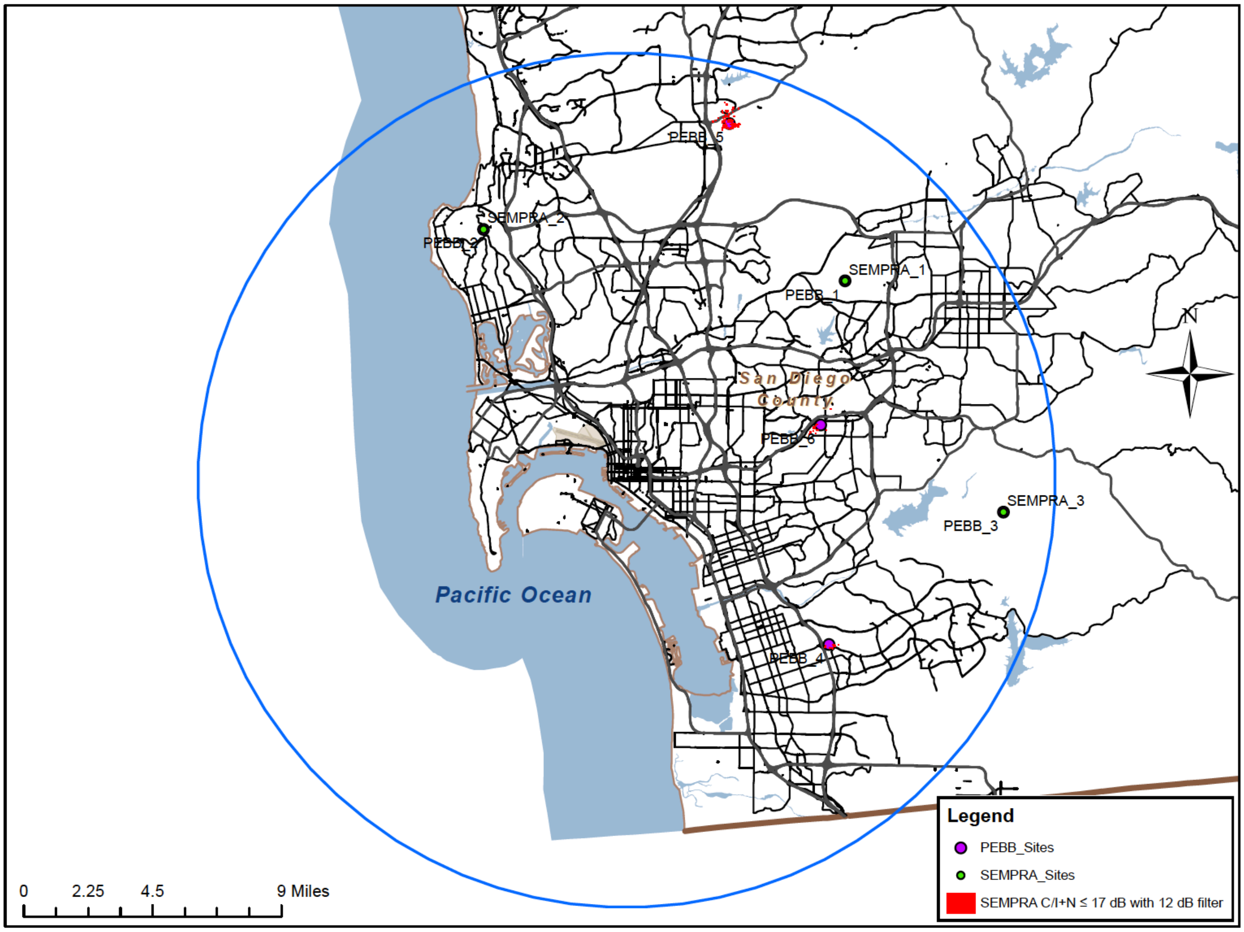

Figure 6 - Downlink OOBE Impact from 6-Site Broadband Network in San Diego (SDG&E) (12 dB Filter)

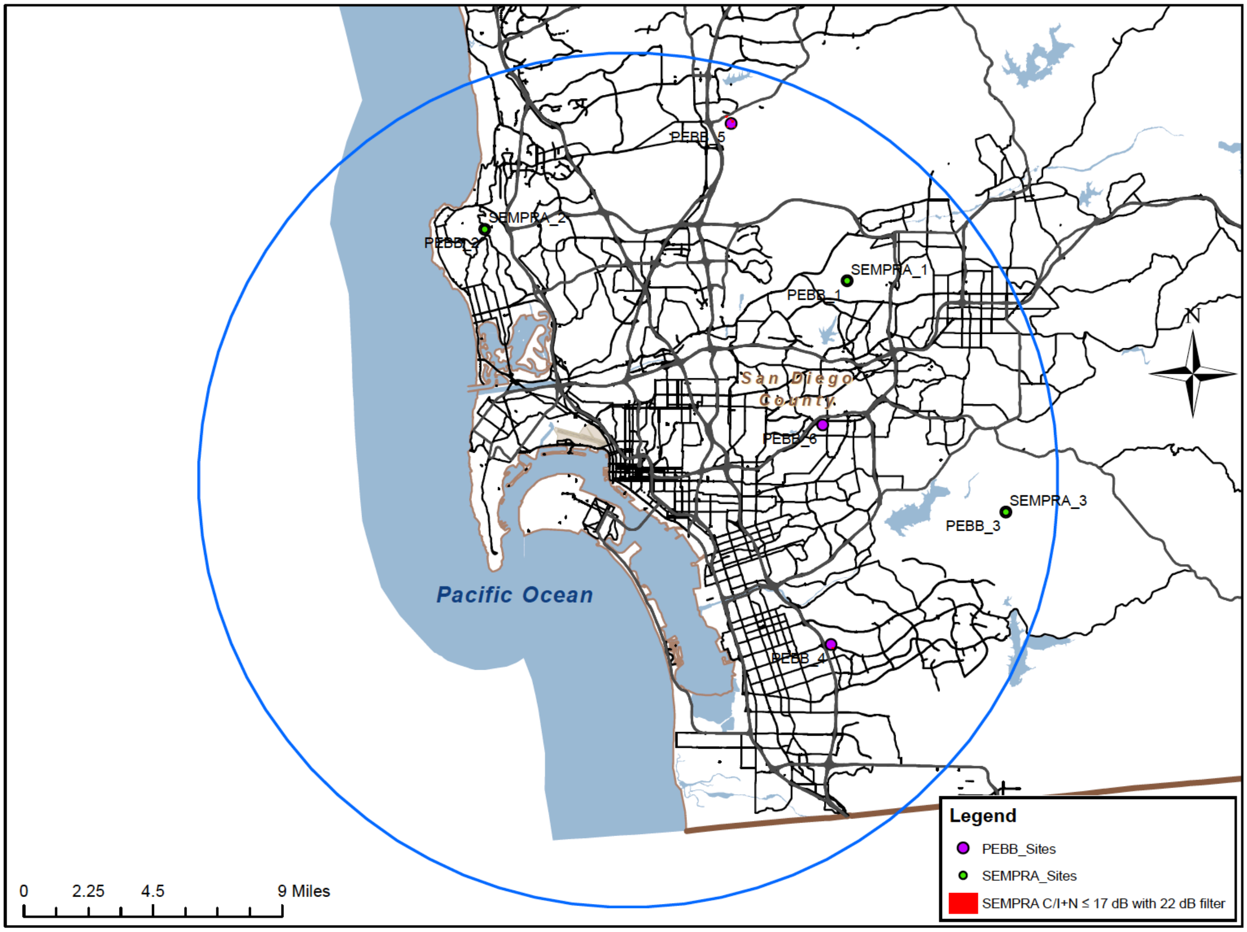

Figure 7 - Downlink OOBE Impact from 6-Site Broadband Network in San Diego (SDG&E) (22 dB Filter)

Table 1 shows the effect of filters for all three markets.

Table 1 - C/(I+N) Less Than 17 dB Due to Downlink OOBE				
Market	**Incumbent**	**Area Affected**	**12 dB Filter**	**22 dB Filter**
San Antonio, TX	LCRA	0.65%	0.023%	0.006%
Orlando, FL	Duke Energy	0.041%	0.00%	0.00%
San Diego, CA	SDG&E	0.11%	0.023%	0.0013%

4.2 Part 90 Uplink OOBE Interference

In the uplink case, we are concerned with out-of-band emissions affecting the receiver at the Part 90 narrowband repeater. Receiver IM and blocking are non-issues on the uplink because broadband subscriber radios are low power (3 Watts or 1 Watt) and the Part 90 incumbent repeater receive antenna is typically high on a tower. Plus, the repeater is typically more robust than a subscriber radio when it comes to IM and blocking.

Because the LTE uplink multiple access scheme is SC-FDMA, only one subscriber in each sector is transmitting in a resource block at a time. The subscriber's out-of-band emissions are also limited to -25 dBm in a 30 kHz bandwidth. This interference can be modeled.

In the worst case, the path from the broadband subscriber interferer to the repeater site is line-of-sight. If we assume a 10 dBd gain antenna at the victim repeater, a -124 dBm 12 dB SINAD sensitivity (TTA assumed), 3 Watts transmitter power, mobile antenna gain of 3 dBd, mobile cable loss of 2 dB, then the minimum path loss required to ensure no more than 1 dB desense is calculated by the following equation:[15]

$$L_{fs} = 137\text{ dBm} - 25\text{ dBm} - 2\text{ dB} + 3\text{dBd} + 2.15\text{ dBi} + 10\text{ dBd} + 2.15\text{ dBi} - 5.5\text{ dB} = 121.8\text{ dB}$$

For a radio frequency of 935 MHz, this free space path loss is equivalent to a range of 31 km. In practice, the victim receiver will see interference from multiple subscribers (i.e., multiple sectors) and most will have some clutter in the path (not line-of-sight), so the interference will not carry nearly as far as 31 km. To assess the uplink interference impact with any accuracy, it is necessary to use computer modeling of the path loss and a summation of the interference power using software like **Infovista™ Planet** or **EDX SignalPro™**. Also, the focus of this study is not whether or not the broadband network causes measurable interference, but whether the interference it creates results in a $C/(I+N)$ less than 17 dB at the incumbent repeater site. Thus, we care not only about potential interfering signals, but also the simultaneous amplitude of the 900 MHz incumbent mobile at the repeater site.

Recall that to model the downlink OOBE case, we made a worst-case assumption that the transmitter always produced -30.5 dBm (in 8.5 kHz bandwidth), regardless of transmitter power or frequency separation. The uplink case is different than the downlink case because the LTE subscriber uses power control. Subscribers close to the cell site generally operate at lower power while subscribers far from the cell site operate at higher power. Self interference and grade of service also affect the subscriber's instantaneous power. To be 3GPP standard-compliant, an LTE mobile subscriber must reduce its out-of-band emissions by at least 1 dB for every 1 dB reduction in power from maximum [10]. For our purposes, we assume that the maximum allowed OOBE of -30.5 dBm occurs at full power. A CSMAC study [11] shows that 98.3% of the time, the transmit power of an LTE subscriber is backed off at least 9 dB. Thus, it is

[15] We assume the receiver requires a C/N of 7 dB to achieve 12 dB SINAD [5], so the thermal noise floor is -124 - 7 = -131 dBm and the level that creates a 1 dB impact is -131 - 6 = -137 dBm. 2.15 dBi is the gain of a dipole. The factor of -5.5 dB accounts for the difference between the IF bandwidth of 8.5 kHz and the measurement bandwidth of 30 kHz.

reasonable to model the LTE subscriber as an interfering emitter transmitting at -30.5 - 9 = -39.5 dBm.

To model uplink interference at the incumbent repeater site and *C/(I+N)*, we first assumed that a single LTE subscriber is equally likely to be located anywhere in the 15-mile radius service area. At each study tile in the service area, the subscriber is modeled as an interference source operating at -39.5 dBm. We then used **EDX SignalPro™** to calculate the interference level created at the repeater site from an interfering LTE subscriber at each of n study tiles. Assuming a 24.3 km (15 mile) study radius and 800 meter tiles, $n = 2{,}899$. Tiles with associated levels less than -137 dBm were filtered out of the sample set. Thermal noise power of -131 dBm (in 8.5 kHz) was added to each interference sample to get *I+N*.

The incumbent mobile is also equally likely to be anywhere in the service area, independent of the location of the LTE subscriber. Similarly, we calculated the incumbent mobile signal level at the repeater site from each of the 2,899 tiles. We then filtered out any tiles resulting in signals less than -105 dBm (our threshold for acceptable service on a fading channel).

We now want to compute the value of *C/(I+N)* in dB for all possible combinations of incumbent signal and interference value. If there are n tiles in the study area, the number of *C/(I+N)* pairs can be as high as n^2 which for our 15-mile study area is over 8.4 million pairs. The probability that a pair has $C/(I+N) < 17$ dB is estimated by dividing the number of pairs with value less than 17 dB by all pairs resulting from the two sample sets (maximum of n^2). This large sample size makes it impractical to consider all permutations of location for 18 or 21 LTE subscribers. Instead, we model a single LTE subscriber and weight this subscriber by a conservative factor to account for multiple simultaneously transmitting subscribers.

We know that there can be as many as 18 (6 LTE sites) or 21 (7 LTE sites) simultaneously transmitting LTE subscribers in the service area, but it is likely that no more than three of these can cause harmful interference based on a simple geometric argument that no more than three sectors are close enough to the incumbent repeater site to cause measurable interference. To test this theory, we weighted the single interferer by a factor of 2, 3 and 9 to see if there were any cases of more than three sectors creating harmful interference. In all three markets, a maximum of two sectors created harmful interference, so we conservatively selected a weighting of 3 or 4.8 dB.

The following study parameters were used in **EDX SignalPro™**:

Mobile antenna height for incumbent and LTE subscriber = 1.6 m
Incumbent subscriber transmit power = 3 W
Incumbent subscriber antenna gain = 0 dBi
LTE subscriber antenna gain = 0 dBi

LTE subscriber OOBE = -25 dBm measured in 30 kHz, -30.5 dBm in 8.5 kHz
Handset backoff = 9 dB
Propagation model = TIA-TSB-88.2-E [6]
Minimum useable incumbent signal = -105 dBm
Study tiles = 2,899
Incumbent receiver noise floor = -131 dBm
Threshold of LTE interference for *de minimis* harm = -137 dBm

Figure 8 shows all the 800 meter interference tiles that when paired with at least one 900 MHz incumbent mobile tile resulted in $C/(I+N) < 17$ dB for the Orlando, FL market for incumbent Duke Energy. Note there are a total of only five harmful interference tiles and all are very close to the incumbent repeater site. While there are only five interference tiles, there are many incumbent mobile tiles associated with each interfering tile. In fact, there are an average of 73 incumbent mobile tiles paired with each LTE interfering tile. For clarity of presentation, the corresponding incumbent tiles are not shown in Figure 8. Similar plots for San Antonio, TX and San Diego, CA are found in Appendix A.

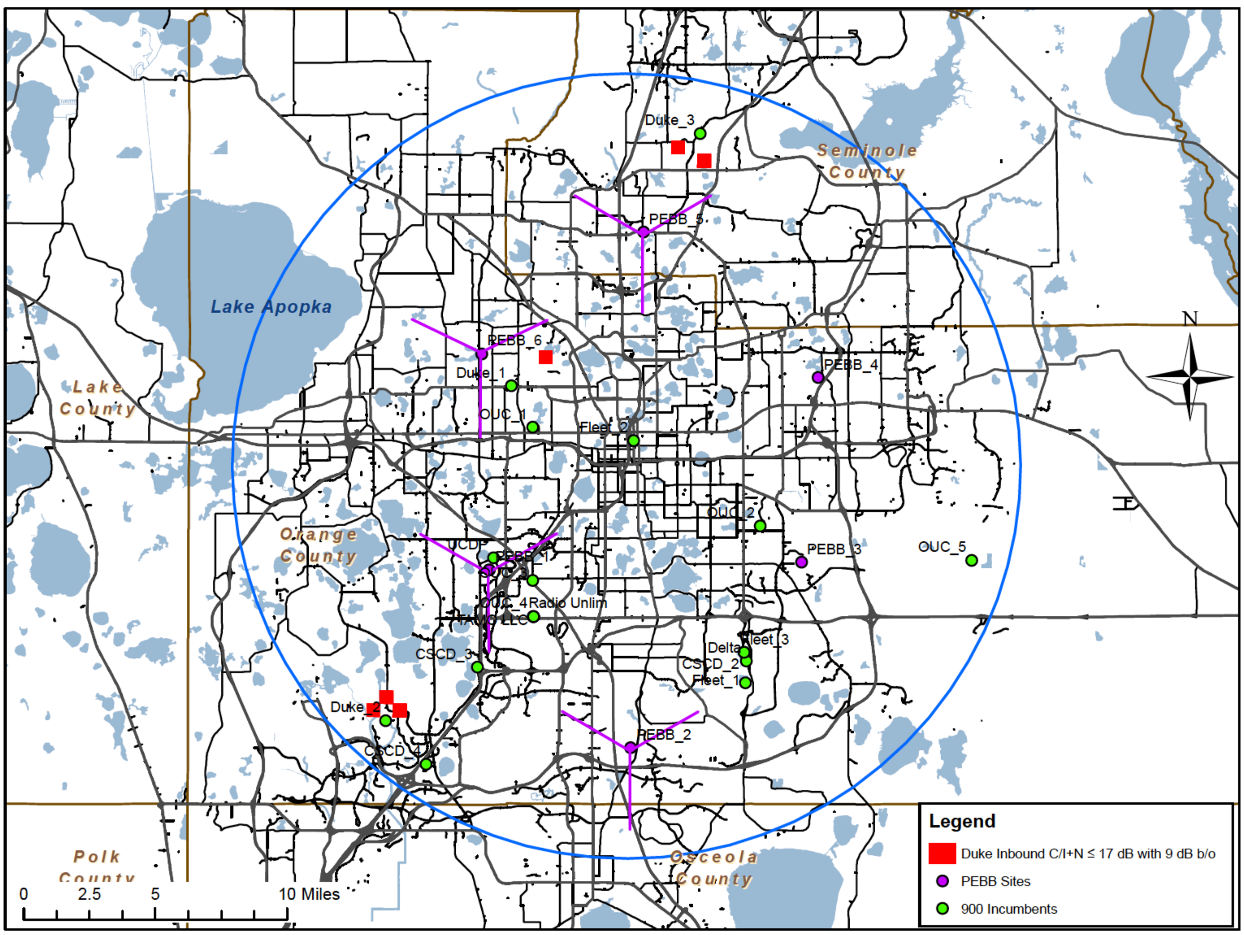

Figure 8 - LTE Uplink Interference to Duke Energy 900 MHz Sites (9 dB backoff)

The uplink interference results for each of three study markets are shown in Table 2. Note that the probability of harmful uplink interference is quite small in all three markets, much less than 1%.[16]

Table 2 - C/(I+N) Less Than 17 dB Due to Uplink OOBE		
Market	**Incumbent**	**P(C/(I+N)) < 17 dB**
San Antonio, TX	LCRA	0.041%
Orlando, FL	Duke Energy	0.025%
San Diego, CA	SDG&E	0.0015%

4.3 Part 90 Transmitter Combiner Issues

Another area of concern for the incumbents is that the new facility must match the ERP of the old facility and this may be difficult to do if channels are packed more closely in the transmitter combiner, thereby creating more insertion loss.

While it is true that tighter channel spacings generally result in greater insertion loss in cavity-ferrite transmitter combiners, it is not clear at the time of this writing whether tighter spacings will actually be required or not. There are too many unknown variables such as how many incumbents must be accommodated in the 2x2 MHz segment (some may elect to move to the broadband service or to another band or service entirely). It is clear, however, there are several effective ways to mitigate the problem:

- According to dBSpectra, a leading vendor of transmitter combiners, modern ceramic cavity filter combiners have at least 1 dB less loss than older combiners like the popular DB8062G for the same frequency spacing [12]. See Figure 9.
- Combiner losses, if they occur, can be made up with higher transmit power (in some cases), greater antenna gain (in some cases) or lower loss coaxial cable (e.g., LDF-7, 1-5/8” diameter versus LDF-5, 7/8” diameter).
- As a last resort, the incumbent’s channels can be split between two combiners (and antennas) to achieve greater frequency spacing.

[16] We believe that even these small values are conservative meaning they over-predict the likelihood of interference. In over 15 years of investigating 800 MHz interference at public safety repeater sites, the author has not encountered one case that could be attributed to cellular subscriber out-of-band emissions.

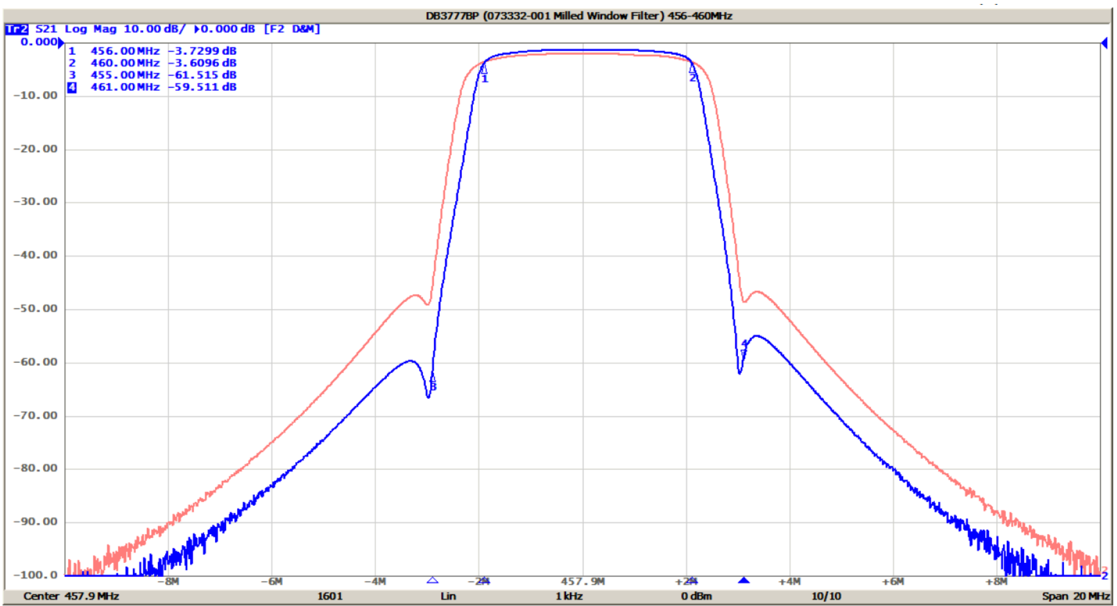

Figure 9 - dBSpectra Bandpass Filter Response (Blue) vs. Legacy Filter (Red) [12]

The FCC addressed this same issue when considering limited 800 MHz replacement capacity in Canadian Border Regions and reached the following conclusion:[17]

> "We recognize that assigning replacement channels to non-ESMR licensees in the manner described above will reduce the potential separation between the upper and lower bounds of available frequencies in the non-ESMR pool, which may require some non-ESMR licensees to make use of more efficient combiners in order to compensate for decreased frequency separation. We note that where more efficient combiners are required for this reason, Sprint must pay the reasonable cost of such combiners under its obligation to provide relocating licensees with comparable facilities."

4.4 Part 90 Downlink Receiver-Induced Interference

The Petitioners proposed a realignment of the 900 MHz band without a guard band between the broadband LTE carrier and narrowband incumbents. It's not automatic that a guard band would eliminate receiver-induced interference, especially because the incumbent receiver has no filter to exploit a guard band and passes the entire 935-940 MHz band. Thus, the broadband carrier will appear at the incumbent receiver LNA with no attenuation (other than an AGC attenuator if one is present). Thus, it is likely that blocking, spectral regrowth or some other impairment will occur and desense the receiver, even if the LTE transmitter is emitting a pristine signal (no OOBE).

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[17] Improving Public Safety Communications in the 800 MHz Band, WT Docket No. 02-55, *Second Report and Order,* 23 FCC Rcd 7605 at ¶19 (2008).

The receiver is a complex system that is difficult to model accurately, so measurements are the best way to characterize receiver performance in the presence of a strong LTE interferer. Bench measurements treat the receiver as a black box and no knowledge of the precise interference mechanism is required. Instead, we simply measure the ability of the receiver to reject the interferer. The resulting Strong Signal Interference (SSI) rejection is simply the difference in dB between the amplitude of the interfering LTE signal and the amplitude of the desired signal required to achieve the minimum level of performance, in our case 12 dB SINAD. The receiver *desense* is defined as the difference in dB between this amplitude of the desired signal and the receiver sensitivity. For example, consider a receiver with measured sensitivity of -120 dBm operating in the presence of an interferer with amplitude -30 dBm. If the receiver has measured SSI rejection of 75 dB at this interferer amplitude, then the desense is -30-75-(-120) = 15 dB. But as long as the receive signal at that location exceeds -105 dBm (static), the receiver is unaffected.

Thus, the measure of goodness for a 900 MHz subscriber radio is not simply the presence or absence of desense. All land mobile radio systems have geographic areas where desense occurs, most often by blocking or receiver IM in the near/far scenario previously discussed. For example, 800 MHz public safety receivers often experience some desense when near 800 MHz cell sites because the receiver front end filter passes frequencies in the cellular band, but as long as the desired signal is sufficient to overcome it, subscriber radio performance is unaffected. Toward that end, there are good performing radios and poor performing radios in this scenario and the good performing radios rarely experience problems because the strong signal interference rejection is high (70 dB or more) even in the presence of very strong interferers.

We know from practical field experience that good performing 800 MHz radios operate trouble-free in virtually all locations despite the presence of strong 800 MHz cellular signals. The Motorola APX-6000/7000, Harris XG-75PE and Tait TP9400 have been measured independently by our firm and are examples of good performing radios. If typical 900 MHz radios perform equally well in the presence of a single LTE carrier, then we can conclude that receiver desense is a manageable problem at 900 MHz.

For this study, Pericle measured SSI rejection of three typical 900 MHz subscriber radios:

Motorola XPR-6580 (analog FM and DMR)
Motorola XPR-7580 (analog FM and DMR)
Motorola APX-4000 (analog FM and P25)

The radios were first bench tested for sensitivity (12 dB SINAD), intermodulation rejection and blocking rejection in accordance with TIA-603-D. Then the radios were tested for SSI rejection using an LTE carrier as the interfering signal. Because our benchmark for acceptable performance is the 800 MHz interference scenario, we also tested each radio under a 900 MHz equivalent scenario with a 1.25 MHz CDMA carrier and a 5 MHz LTE carrier spaced at the same separation as the 800 MHz band. The single 3 MHz LTE carrier performance and the 800 MHz emulation were plotted and compared to determine if the 900 MHz is worse or better than the more familiar 800 MHz scenario. A spectrum analyzer trace of the 800 MHz scenario at 900 MHz is shown in Figure 10.

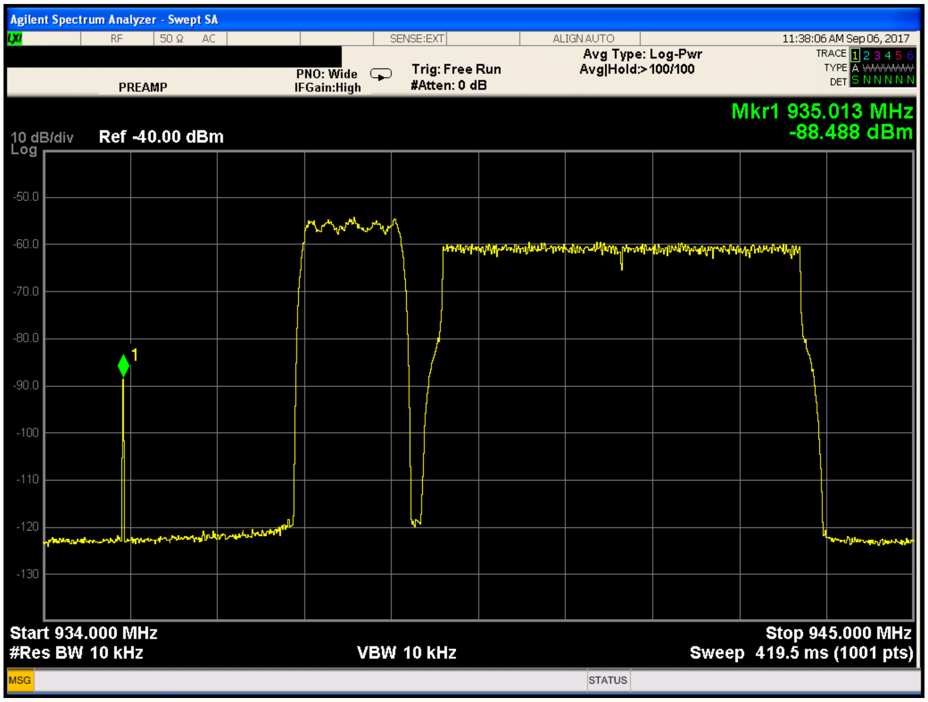


Figure 10 - 800 MHz Scenario at 900 MHz (equal power interferers)

Subscriber radios were tested in accordance with the test plan found in Appendix B to this white paper. The TIA-603-D test results for each radio are found in Table 3. The values in Table 3 are for Channel 159, 936.9875 MHz. Blocking rejection was measured at +/- 1 MHz separation.

Table 3 - TIA-603-D Test Results for 900 MHz Subscribers

Radio	Sensitivity (dB)	IM Rejection (dB)	Blocking Rejection (dB)
XPR-6580	-120.2	76.7	99.7
XPR-7580	-121.8	78.8	101.3
APX-4000	-121.2	77.7	101.7

The XPR-6580 and the APX-4000 both include an RF AGC feature with three optional settings: Disabled, Standard and Enhanced. These radios were set to “Standard” for these measurements.
The SSI rejection performance for the XPR-6580, XPR-7580 and APX-4000 are found in

Figures 11, 12 and 13, respectively. Note that the 800 MHz scenario is also plotted in each case.

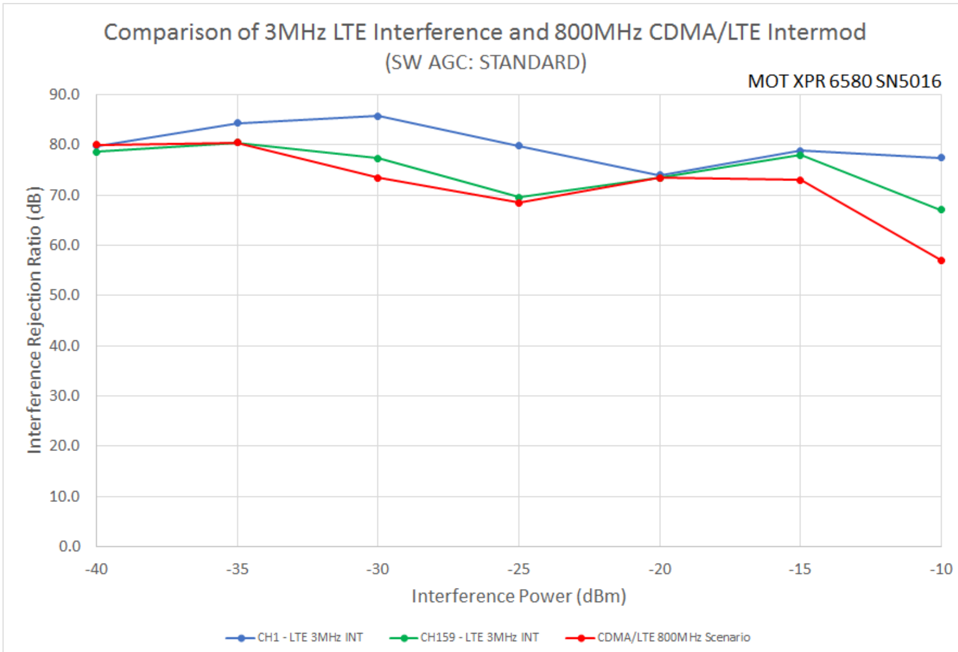


Figure 11 - XPR-6580 SSI Rejection

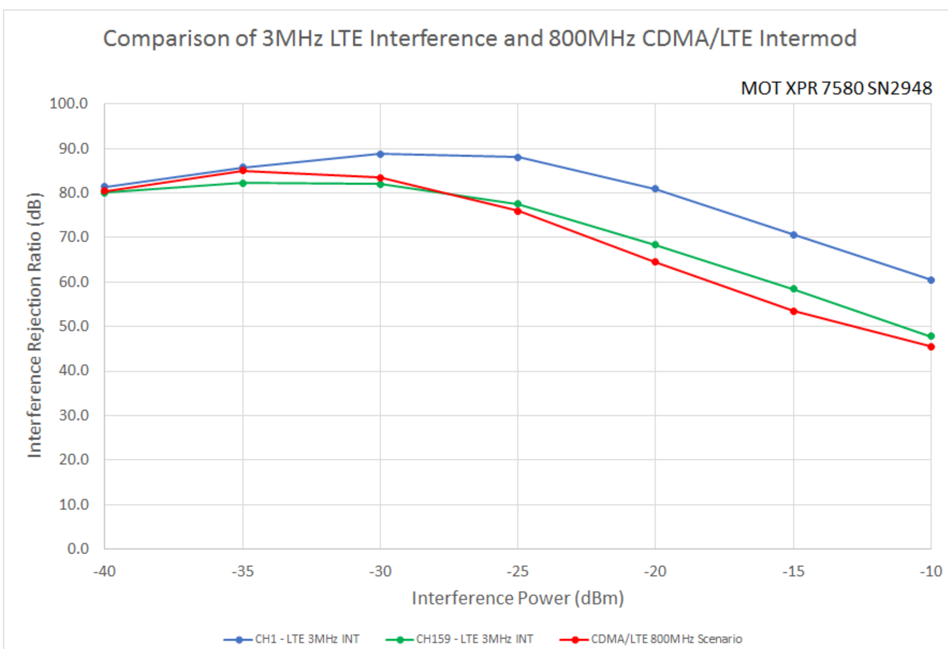


Figure 12 - XPR-7580 SSI Rejection

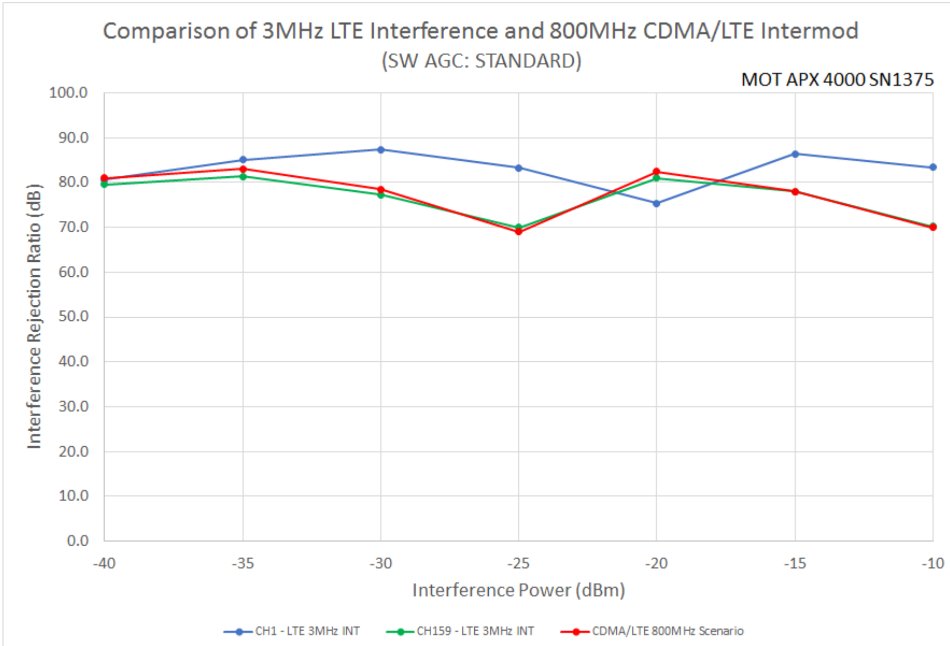


Figure 13 - APX-4000 SSI Rejection

These four plots reveal some interesting results. First, Channel 1, which is nearly 2 MHz from the broadband segment edge, shows better performance than Channel 159 which is only 12.5 kHz from the broadband segment edge. This behavior is expected if the interference is spectral regrowth as this type of interference tends to roll off with greater frequency separation. More important is the performance of Channel 159 relative to the 800 MHz scenario. For every radio tested and for almost all samples, the 900 MHz scenario performance (3 MHz LTE carrier) matches or exceeds the 800 MHz scenario performance. In other words, the 900 MHz incumbent subscriber, who has no guard band, faces an interference situation that is no worse (and in some cases better) than the 800 MHz user who benefits from a 2 MHz guard band. If the 800 MHz scenario is acceptable to public safety users for good performing radios, then the 900 MHz scenario proposed by the Petitioners should also be acceptable for good performing radios. The XPR-6580, XPR-7580 and APX-4000 are good performing radios by industry standards.[18]

Beyond these results, it is interesting to note that the XPR-6580, an older model, outperforms the XPR-7580. The superior performance of the XPR-6580 is probably due to its software RF AGC feature which the XPR-7580 lacks. The APX-4000 also offers an advanced RF AGC feature and its superior performance is demonstrated at the highest interferer amplitudes. This feature is not

[18] At 800 MHz, good performing radios include the APX-6000, APX-7000, APX-4000, Harris XG-75PE and Tait TP9400. The measure of a good performing radio in the presence of Strong Signal Interference (SSI) is its ability to operate impact-free under typical urban conditions. A rule of thumb is the radio should operate with at least 60 dB SSI rejection for interfering power levels from -40 to -13 dBm (equivalent to 3,000 μW/m², see Appendix D for derivation). Based on our field experience, radios that perform at this level rarely experience problems from SSI.

widely known in the industry, *but it is important that 900 MHz subscriber radios be programmed to activate this feature*.

5.0 Potential Interference to Part 24 Incumbents

FCC Part 24 governs the 901-902, 940-941 MHz band, known as the Narrowband PCS (NPCS) band. Sensus Metering Systems is an AMI manufacturer whose equipment operates in this band. During the petition proceeding, Sensus provided a document with many of its relevant base station radio specifications [9]. The Sensus system employs thousands of fixed metering units (subscribers or *endpoints*) and several collection points (base stations or *Tower Gateway Base Station, TGB*). The Sensus base station has sensitivity, bandwidth and blocking specifications similar to a high-performing land mobile radio repeater.

Because the Part 24 band is primarily licensed by market rather than by site, Sensus is not required to disclose the locations of its collection sites and it is not possible to model its network as we did for Part 90 users in San Antonio, Orlando and San Diego. However, if the endpoints are similar to land mobile radios, the conclusions are likely to be the same as for Part 90 incumbents.

Sensus must already operate in the presence of high power Part 90 incumbents so the only relevant question is how does the broadband system differ from Part 90 incumbents? We know the worst case OOBE is actually lower than incumbents (-25 dBm versus -13 dBm), but it is possible that the PEBB licensee will employ a greater number of cell sites and that the average antenna height may be lower. So, downlink potential interference might be greater unless additional filtering is used. This is the same conclusion we reached for Part 90 incumbents.

In many ways the Part 24 interference problem is symmetrical to the Part 90 incumbent problem so the same mitigation techniques for downlink interference apply: filtering, suppressed sidelobe antenna patterns and co-location.

Similarly for uplink interference, if the collection points are located at high points like the Part 90 repeater sites, uplink interference from LTE subscribers should be low and manageable.

6.0 Proposed Rules in FCC Part 90

Ensuring incumbent Part 90 and Part 24 users can successfully operate in the presence of a broadband 900 MHz carrier is a two-part process: The first part is to impose limitations on the broadband transmitter to preclude interference in the vast majority of cases (primarily through the emission mask and a maximum power flux density on the ground). The second part is to create rules to resolve interference problems in the rare cases when they occur. The strongest precedents for such rules are § 90.672 and recently adopted § 22.913 which address interference to narrowband 800 MHz users from cellular 800 MHz base stations. Accordingly, we propose the following regulatory language:

Subpart S—Regulations Governing Licensing and Use of Frequencies in the 806-824, 851-869, 896-901, and 935-940 MHz Bands

§90.672. Unacceptable interference to non-cellular 800 MHz licensees from 800 MHz cellular systems or part 22 Cellular Radiotelephone systems, and within the 900 MHz Business/Industrial Land Transportation Pool.

Change (a)(1)(i)(A) to:

(A) A median desired signal strength of −104 dBm or higher if operating in the 800 MHz band, or a median desired signal strength of ~~−88~~ **-98** dBm if operating in the 900 MHz B/ILT Pool, as measured at the R.F. input of the receiver of a mobile unit; or ...

Change (a)(1)(i)(B) to:

(B) A median desired signal strength of −101 dBm or higher if operating in the 800 MHz band, or a median desired signal strength of ~~−85~~ **-95** dBm if operating in the 900 MHz B/ILT Pool, as measured at the R.F. input of the receiver of a portable i.e., hand-held unit; and either ...

(b) [no change]

Add the following paragraphs to Part 90 in the appropriate subparts that create the PEBB service:[19]

(a) *Power limitations.*[20]

(1) Broadband Fixed and Base Station power spectral density (PSD) in the 935-940 MHz band are limited as follows:

(a) 400 W/MHz ERP in non-rural areas, and 800 W/MHz ERP in rural areas, without a power flux density (PFD) requirement.

(b) Higher PSD limits. To ensure flexibility in the deployment of broadband service beyond the ERP limits outlined in (1)(a) that would limit coverage and potential inability to deliver broadband services, broadband operators would be allowed, with the PFD rules outlined in (1)(d) to deploy at PSD levels outlined in (1)(c). A five year sunset timeframe would allow for the evolution and adoption of

[19] The author understands that additional rules are needed to establish the PEBB service. The proposed rules herein are intended to address the narrower issues of co-existence with narrowband incumbents, prevention of harmful interference and remedies for the incumbent should harmful interference occur.

[20] To harmonize with FCC § 22.913 (800 MHz Cellular Radiotelephone Service).

narrowband LMR technologies that enable operations adjacent to broadband systems without a PFD limit.

(c) Higher power broadband rules: up to 1000 W/MHz ERP in non-rural areas, and up to 2000 W/MHz ERP in rural areas with a five year PFD limit and an advance notification requirement.

(d) Higher power broadband PFD limit of 3,000μW/m^2 not to be exceeded over 98 percent of the served area within 1 km of the base station as measured 1.6 meters above ground.

(2) PEBB Control and Mobile Stations operating in the 896-901 MHz band up to 10W ERP.

(3) PEBB Portable stations operating in the 896-901MHz band up to 3W ERP.

(b) *Emission mask requirements for 900 MHz broadband fixed stations*. For any frequency below 937 MHz and above 940 MHz, the power of any emission shall be attenuated below the transmitter power (P) in watts by at least $50+10\log_{10}(P)$ decibels measured in a 100 kHz bandwidth.

(c) *Emission mask requirements for 900 MHz broadband mobile subscriber stations*. For any frequency below 898 MHz and above 901 MHz, the power of any emission shall be attenuated below the transmitter power (P) in watts by at least $50+10\log_{10}(P)$ decibels measured in a 100 kHz bandwidth.

(d) *Advance notification requirement for 898-901 MHz/937-940 MHz broadband service*. At least 30 days but not more than 90 days prior to activating a broadband cell site permitted under paragraph (xx) of this section, the broadband licensee must provide written advance notice to any Part 90 B/ILT and SMR MTA licensee authorized in the frequency range 896-898 MHz/935-937 MHz or Part 24 licensee authorized in the frequency range 901-902 MHz/940-941 MHz with a fixed site (or market edge for market-based licensees) located within a radius of 113 km of the broadband base station to be deployed. The written notice shall be required only one time for each such broadband cell site and is for informational purposes only; the 900 MHz or Part 24 narrowband licensees are not afforded the right to accept or reject the activation or to unilaterally require changes in the operating parameters. The written notification must include the base station's location, ERP, height of the transmitting antenna's center of radiation above ground level, and the timeframe for activation, as well as the PEBB licensee's contact information. Additional information shall be provided by the PEBB licensee upon request of a 900 MHz or Part 24 narrowband licensee required to be notified under this paragraph.

7.0 Conclusions and Recommendations

The purpose of this white paper is to characterize the potential technical impacts of a 900 MHz realignment and to clearly explain industry best practices, commercially available equipment, and suggested methodologies that can be applied to enable existing narrowband licensees to be relocated to the 2x2 MHz segment while maintaining or improving their existing system performance.

Both transmitter out-of-band emissions and receiver-induced interference were modeled and analyzed.

To understand the effect of out-of-band emissions, we modeled 900 MHz incumbent desired signals from actual sites and hypothetical broadband LTE interference from a prospective network. Three markets were modeled: San Antonio, TX; Orlando, FL and San Diego, CA. For broadband downlink interference, we found that out-of-band emissions resulted in *C/(I+N)* less than 17 dB (an FCC minimum standard) in a small number of study tiles (less than 1%), in all three markets.

In the rare case where harmful downlink interference might occur, the PEBB provider should consider four mitigations to address this potential problem:

- Avoid siting broadband antennas close to the ground
- Co-locate the broadband cell site with the incumbent when possible
- Employ broadband cell site antennas with suppressed sidelobes
- Install bandpass cavity filters with greater rejection outside the 3 MHz segment

If practical, we recommend the use of 12 dB or 22 dB rejection cavity filters and suppressed sidelobe antennas as these techniques should reduce downlink interference cases to a small and manageable number.

Uplink out-of-band emissions interference is also a potential problem, but characterizing it with any accuracy is more difficult due to limitations of modeling tools, limited computing power, difficulty modeling power control effects and the basic physics of the problem. Despite these hurdles, we were able to model uplink interference and estimate the number of cases where the *C/(I+N)* at the Part 90 repeater site is less than 17 dB. We found that in all three markets, much less than 1% of the service area was affected, a similar result to the downlink interference case.

Receiver-induced interference rejection (from blocking and spectral regrowth) was measured on the bench for four typical 900 MHz subscriber radios. We found that performance is no worse than the well-known 800 MHz case which is generally considered acceptable provided good performing radios are used. This is an interesting and far-reaching result because performance at 900 MHz with a single LTE carrier and no guard band is as good as performance at 800 MHz with two broadband carriers and a 2 MHz guard band. For radios with an RF AGC feature, it is important that this feature be turned on.

We also recommend that the FCC adopt language similar to that adopted in the 2004 800 MHz rebanding rulemaking [4] and the more recent 800 MHz cellular band ERP rulemaking [8] to protect incumbents from interference and to provide remedies when interference occurs. Specific rule language is proposed in Section 6.0 of this report.

8.0 References

[1] Petition for Rulemaking of the Enterprise Wireless Alliance and Pacific Datavision, Inc., RM-11738 (filed Nov. 17, 2014).

[2] Wireless Telecommunications Bureau Seeks Comment on Enterprise Wireless Alliance and Pacific Datavision, Inc. Petition for Rulemaking Regarding Realignment of 900 MHz Spectrum, Public Notice, RM-11738, , November 26, 2014 (terminated on August 4, 2017).

[3] FCC Technological Advisory Council, Interference Limits Policy, "The use of harm claim thresholds to improve the interference tolerance of wireless systems," White Paper, February 6, 2013.

[4] Improving Public Safety Communications in the 800 MHz Band, Consolidating the 900 MHz Industrial/Land Transportation and Business Pool Channels, Report and Order, Fifth Report and Order, Fourth Memorandum Opinion and Order, and Order, WT 02-55, FCC 04-168, August 6, 2004.

[5] TIA TSB-88.1-D, "Wireless Communications Systems — Performance in Noise and Interference-Limited Situations, Part 1: Recommended Methods for Technology-Independent Performance Modeling," April, 2012.

[6] TIA TSB-88.2-E, "Wireless Communications Systems — Performance in Noise and Interference-Limited Situations, Part 2: Propagation and Noise," January, 2016.

[7] TIA TSB-88.3-D, "Wireless Communications Systems — Performance in Noise and Interference-Limited Situations, Part 3: Recommended Methods for Technology-Independent Performance Verification," October, 2013, Addendum 1, February 2017.

[8] FCC Second Report and Order, Report and Order, and Second Further Notice of Proposed Rulemaking, WT Docket No. 12-40, March 2, 2017.

[9] Sensus Metering Systems, "Flexnet System Details."

[10] 3GPP TSG-RAN4 #59AH, R4-113745, B26 Uplink LTE UE to PS BS co-existence, Bucharest, Romania, 27th June to 1st July, 2011.

[11] Commerce Spectrum Management Advisory Committee (CSMAC) Final Report: Working Group 1 – 1695-1710 MHz Meteorological-Satellite, Appendix 3: Baseline LTE Uplink Characteristics, January 22, 2013.

[12] dBSpectra TechBook series, "RF Filters," Figure 9.

[13] Review of the Commission's Rules Governing the 896-901/935-940 MHz Band, Realignment of the 896-901/935-940 MHz Band to Create a Private Enterprise Broadband Allocation, Amendment of the Commission's Rules to Allow for Specialized Mobile Radio Services Over 900 MHz Business/Industrial Land Transportation Frequencies, Notice of Inquiry, FCC 17-108, WT Docket 17-200, August 4, 2017.

9.0 Acronyms

3GPP	3rd Generation Partnership Project (a standards committee)
AES	Advanced Encryption Standard
AGC	Automatic Gain Control
AGL	Above Ground Level
AMI	Advanced Metering Infrastructure
AMSL	Above Mean Sea Level
APCO	Association of Public Safety Communications Officers
AWGN	Additive White Gaussian Noise
BDA	Bi-Directional Amplifier
BER	Bit error rate
CDMA	Code Division Multiple Access
CII	Critical Infrastructure Industry
CPC	Channel Performance Criterion
CSMAC	Commerce Spectrum Management Advisory Committee
DAQ	Delivered Audio Quality
dB	Decibel
dBi	Decibels relative to isotropic (for antenna gain)
dBd	Decibels relative to a half-wave dipole (for antenna gain)
dBm	Decibels relative to a milliwatt
DMR	Digital Mobile Radio
EIRP	Effective Isotropic Radiated Power
ENBW	Equivalent Noise Bandwidth
ERP	Effective Radiated Power (relative to half-wave dipole)
ESMR	Enhanced Specialized Mobile Radio
EWA	Enterprise Wireless Alliance
FCC	Federal Communications Commission
FDMA	Frequency Division Multiple Access
FM	Frequency Modulation
GHz	Gigahertz (10^9 cycles per second)
GPS	Global Positioning System

HAAT	Height Above Average Terrain
IF	Intermediate Frequency
IM	Intermodulation
ITU	International Telecommunications Union
LCRA	Lower Colorado River Authority
LMR	Land Mobile Radio
LNA	Low Noise Amplifier
LTE	Long Term Evolution (4G cellular standard)
MHz	Megahertz (10^6 cycles per second)
MIMO	Multiple Input, Multiple Output (an antenna diversity scheme)
MTA	Major Trading Area
NLCD	National Land Clutter Database
NOI	Notice of Inquiry
NPCS	Narrowband PCS (FCC Part 24, 901-902, 940-941 MHz)
NPSPAC	National Public Safety Planning Advisory Committee
ODU	Outdoor Unit
OFDM	Orthogonal Frequency Division Multiplex
OFDMA	Orthogonal Frequency Division Multiple Access (LTE downlink)
OOBE	Out-of-Band Emissions
P25	APCO Project 25 (interoperability standard)
PEBB	Private Enterprise Broadband
PFD	Power Flux Density (usually expressed in units of $\mu W/m^2$)
PIM	Passive Intermodulation
PLMR	Private Land Mobile Radio
PMI	Preventive Maintenance Inspection
PSD	Power Spectral Density (usually expressed as Watts/MHz)
PSEG	Public Service Electric and Gas
QPSK	Quadrature Phase Shift Keying
RB	Resource Block
RF	Radio Frequency
RSSI	Radio Signal Strength Indicator
SAR	Service Area Reliability
SC-FDMA	Single Channel Frequency Division Multiple Access (LTE uplink)
SDG&E	San Diego Gas & Electric
SMR	Specialized Mobile Radio
SNUG	Sensus FlexNet User Group
SSI	Strong Signal Interference
SSIM	Strong Signal Intermodulation
TDI	Time Delay Interference (in simulcast networks)
TDMA	Time Division Multiple Access
TGB	Total Gateway Base Station

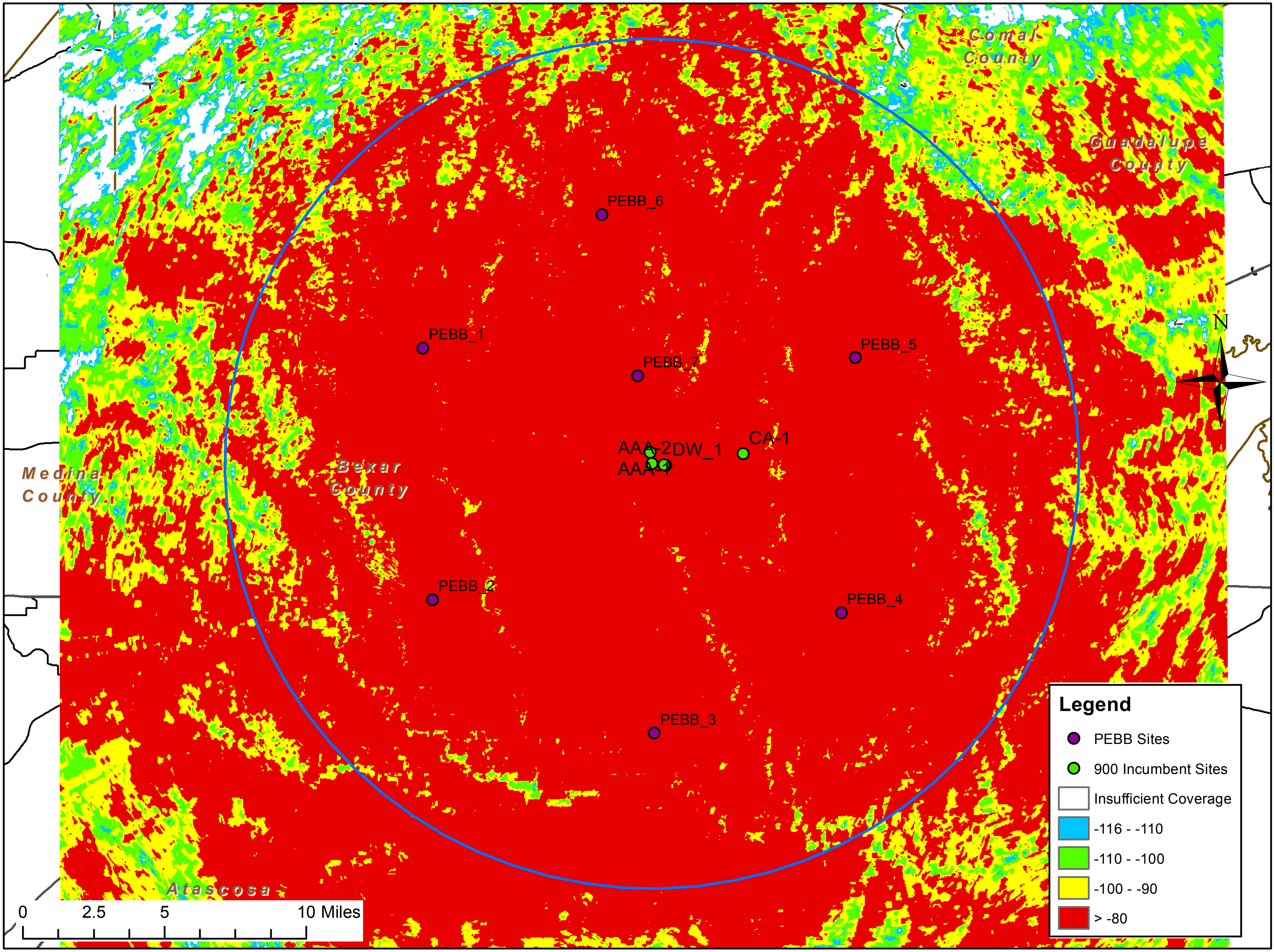
TIA	Telecommunications Industries Association
TTA	Tower-Top Amplifier
UHF	Ultra High Frequency (300 MHz to 3 GHz)
ULS	FCC Universal Licensing System
UMTS	Universal Mobile Telecommunications Service (a 3G Service)
VHF	Very High Frequency (30 MHz to 300 MHz)

Appendix A - Coverage & Interference Plots

San Antonio, TX; Orlando, FL; San Diego, CA

Appendix A.1 - Coverage & Interference Plots for San Antonio, TX

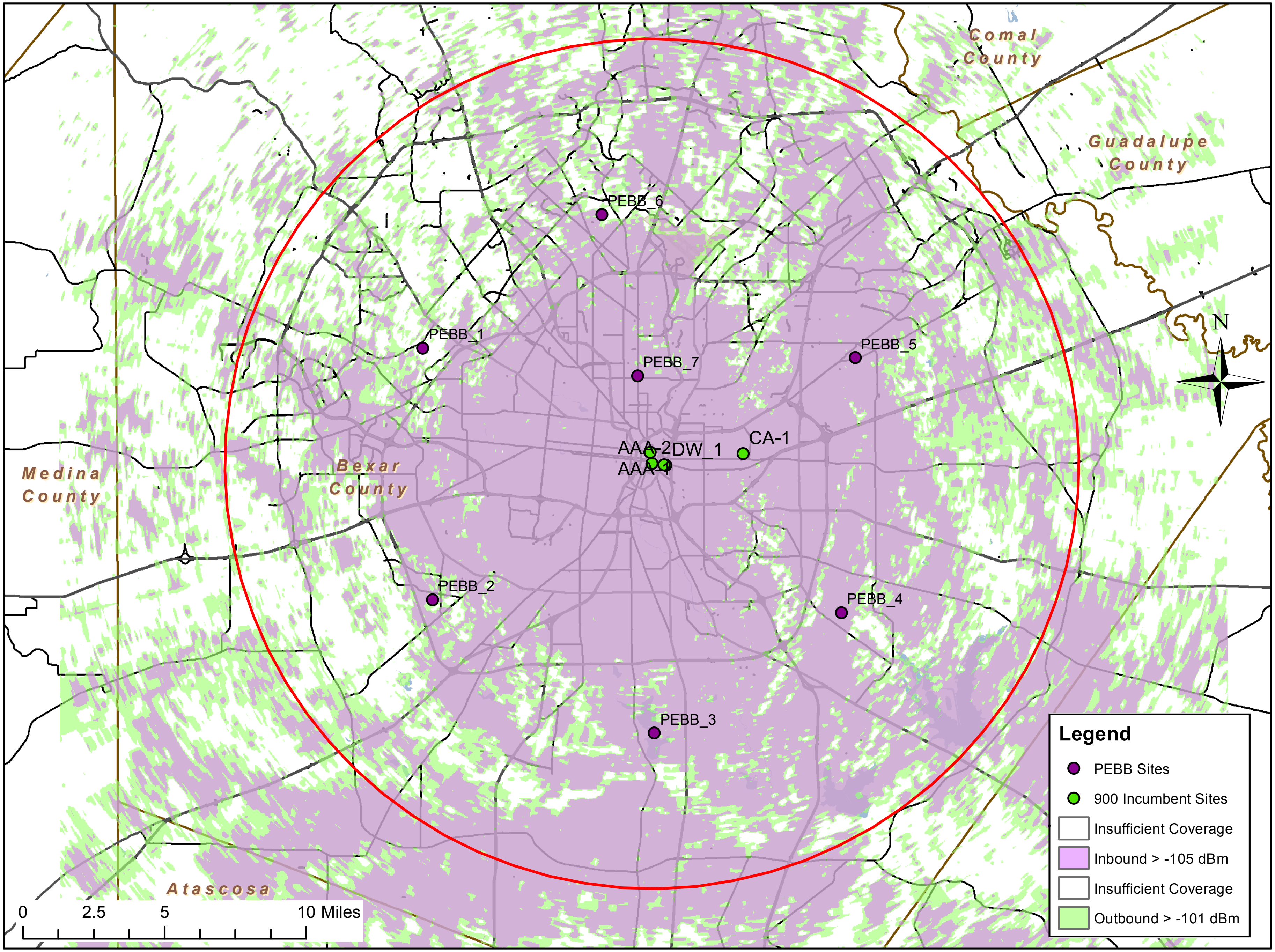
PEBB Coverage Heatmap



Pericle Communications Company

May 3, 2017

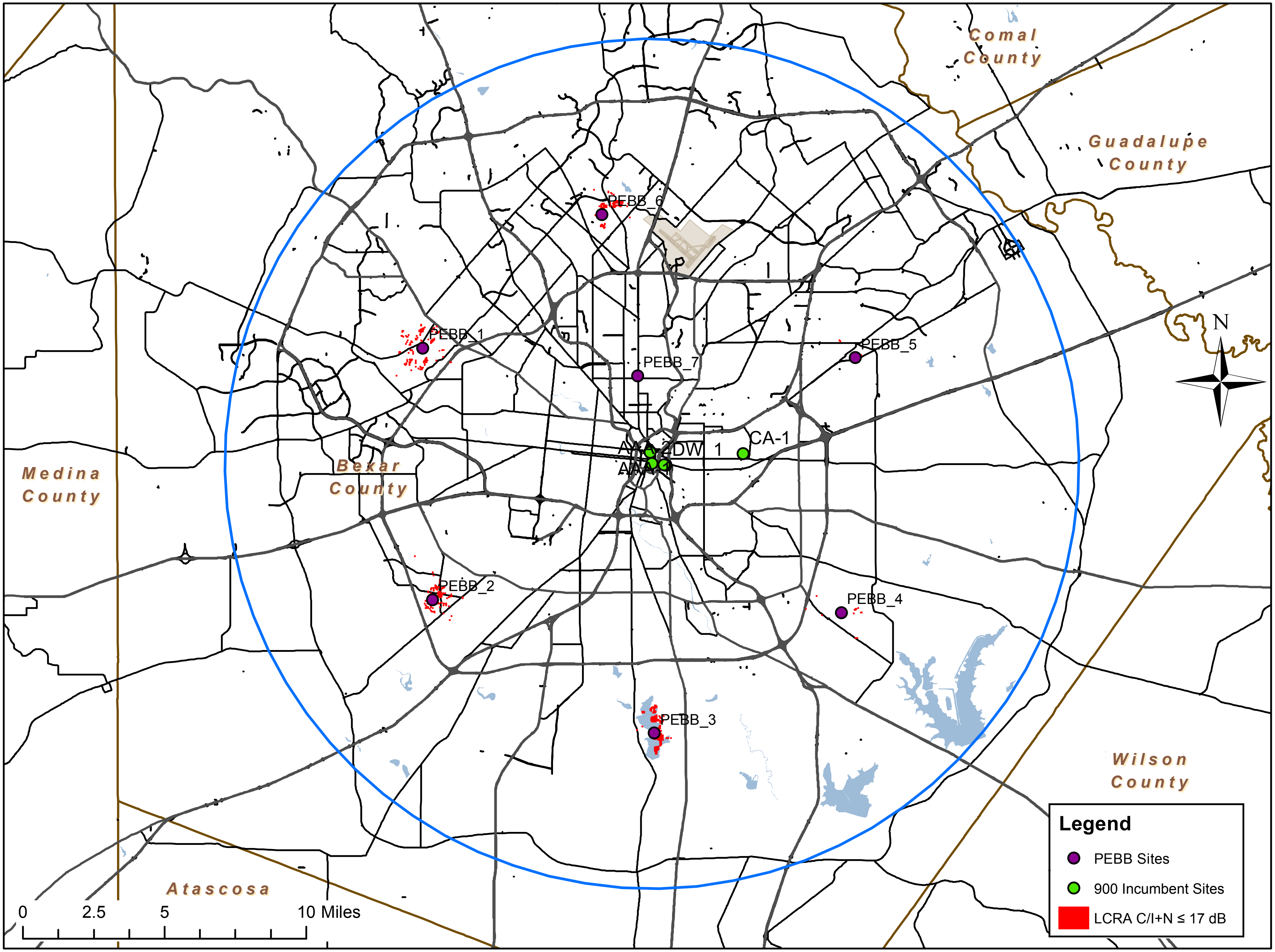
LCRA Coverage



Pericle Communications Company

May 3, 2017

LCRA Downlink Interference



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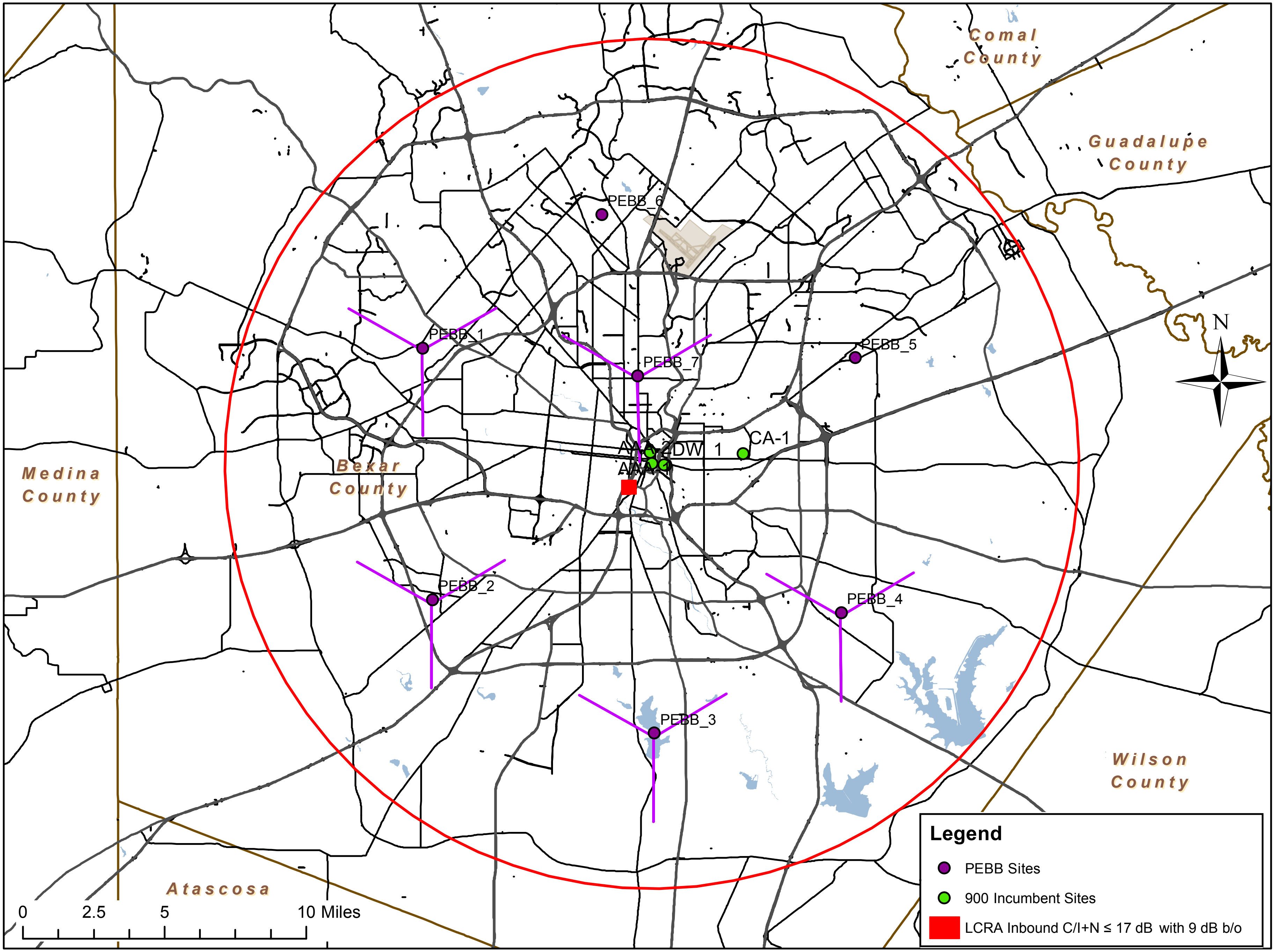
May 3, 2017

LCRA Uplink Interference (3 LTE Users)

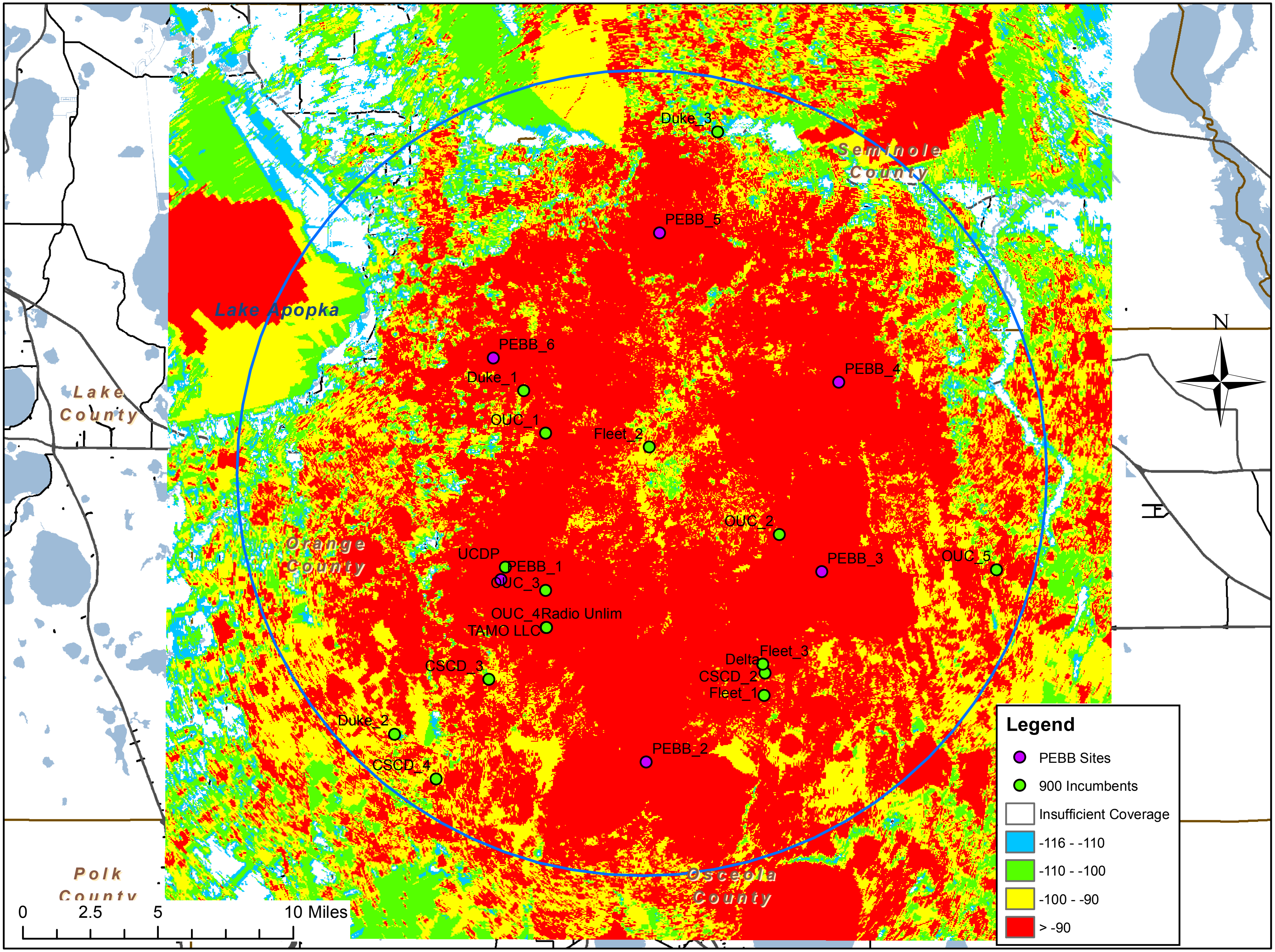


Pericle Communications Company

May 3, 2017

Appendix A.2 - Coverage & Interference Plots for Orlando, FL

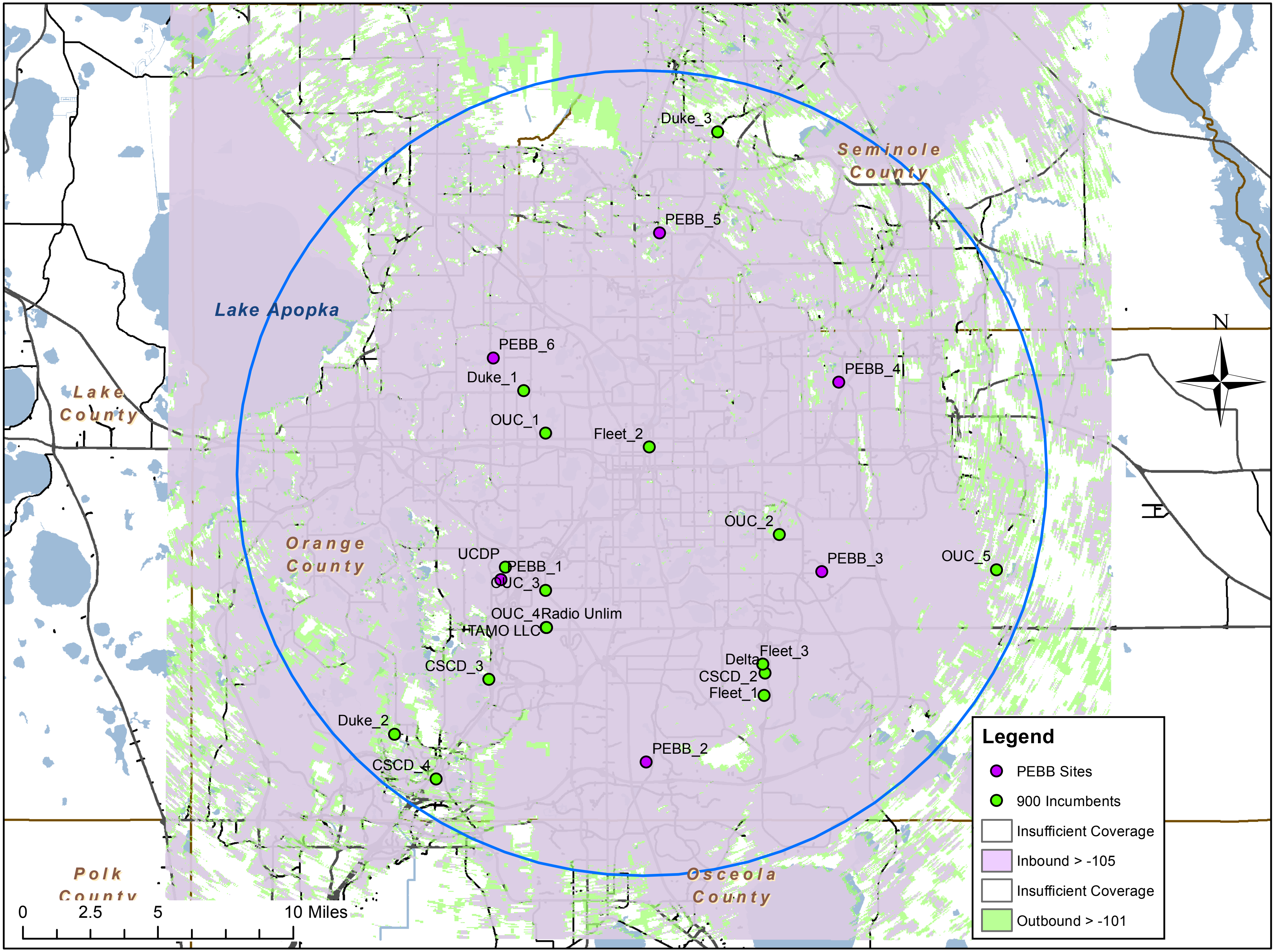
PEBB Coverage Heatmap



Pericle Communications Company

May 3, 2017

Duke Energy Coverage



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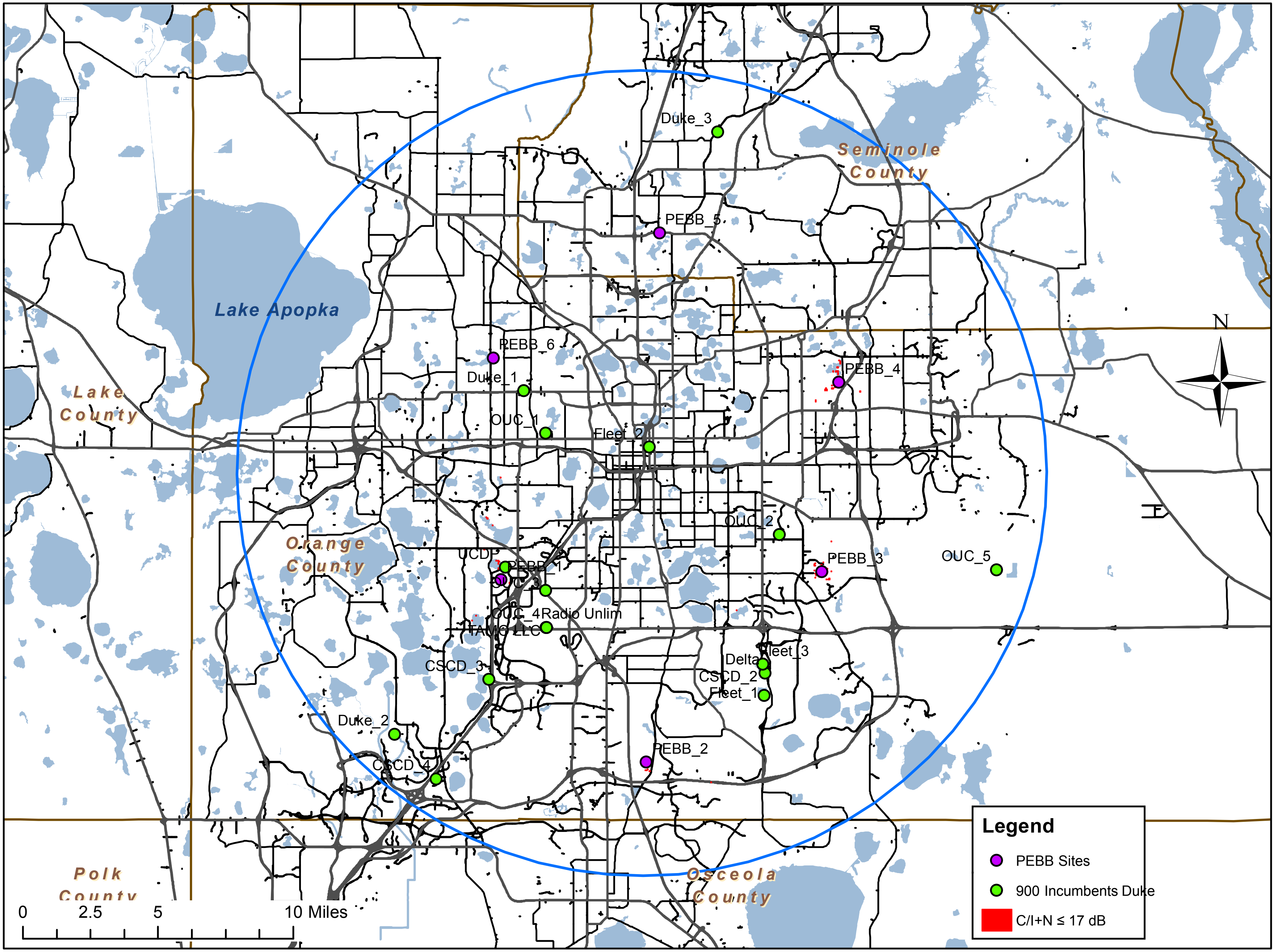
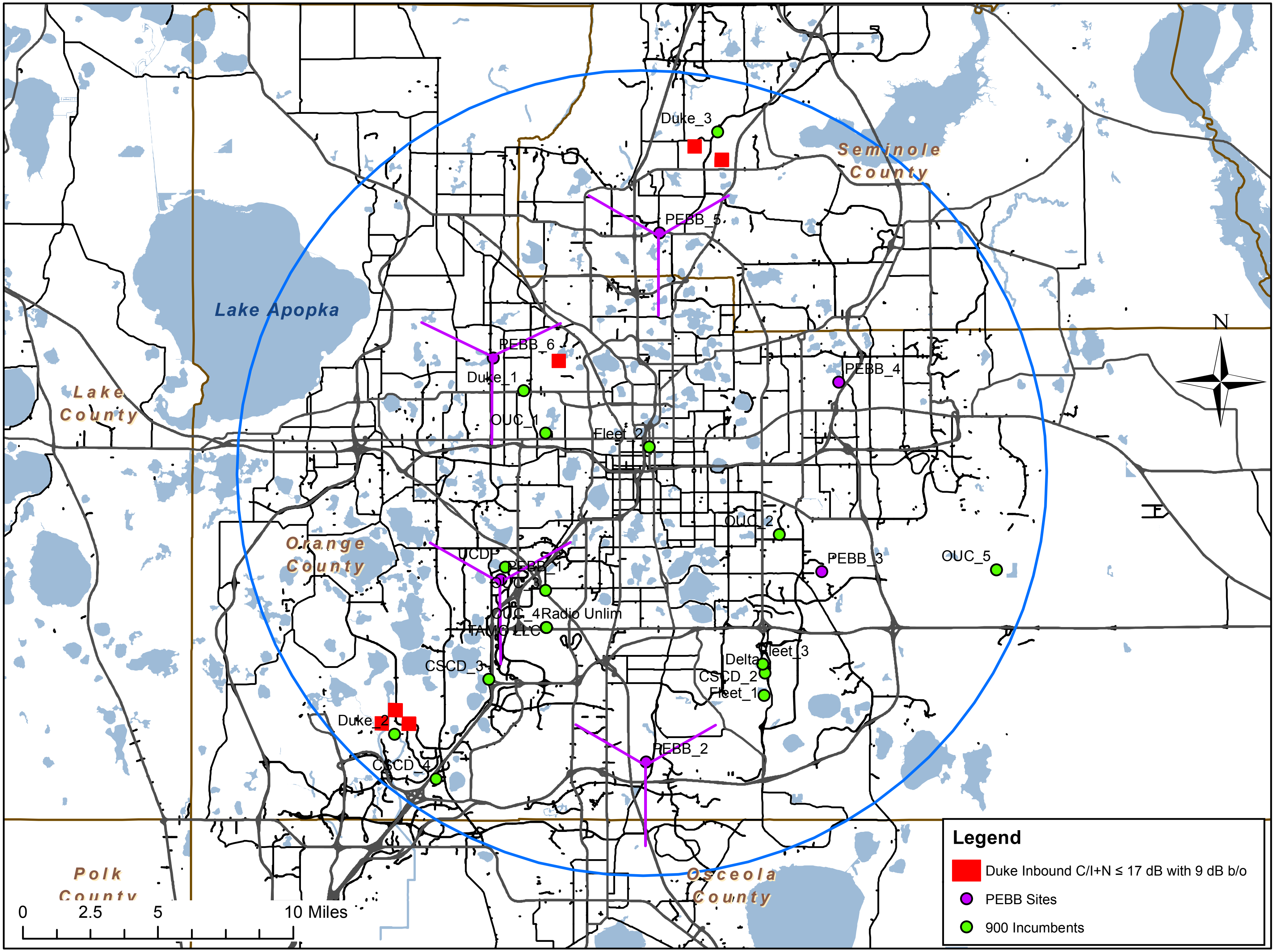
Duke Energy Downlink Interference



Pericle Communications Company

May 3, 2017

Duke Energy Uplink Interference(3 LTE Users)

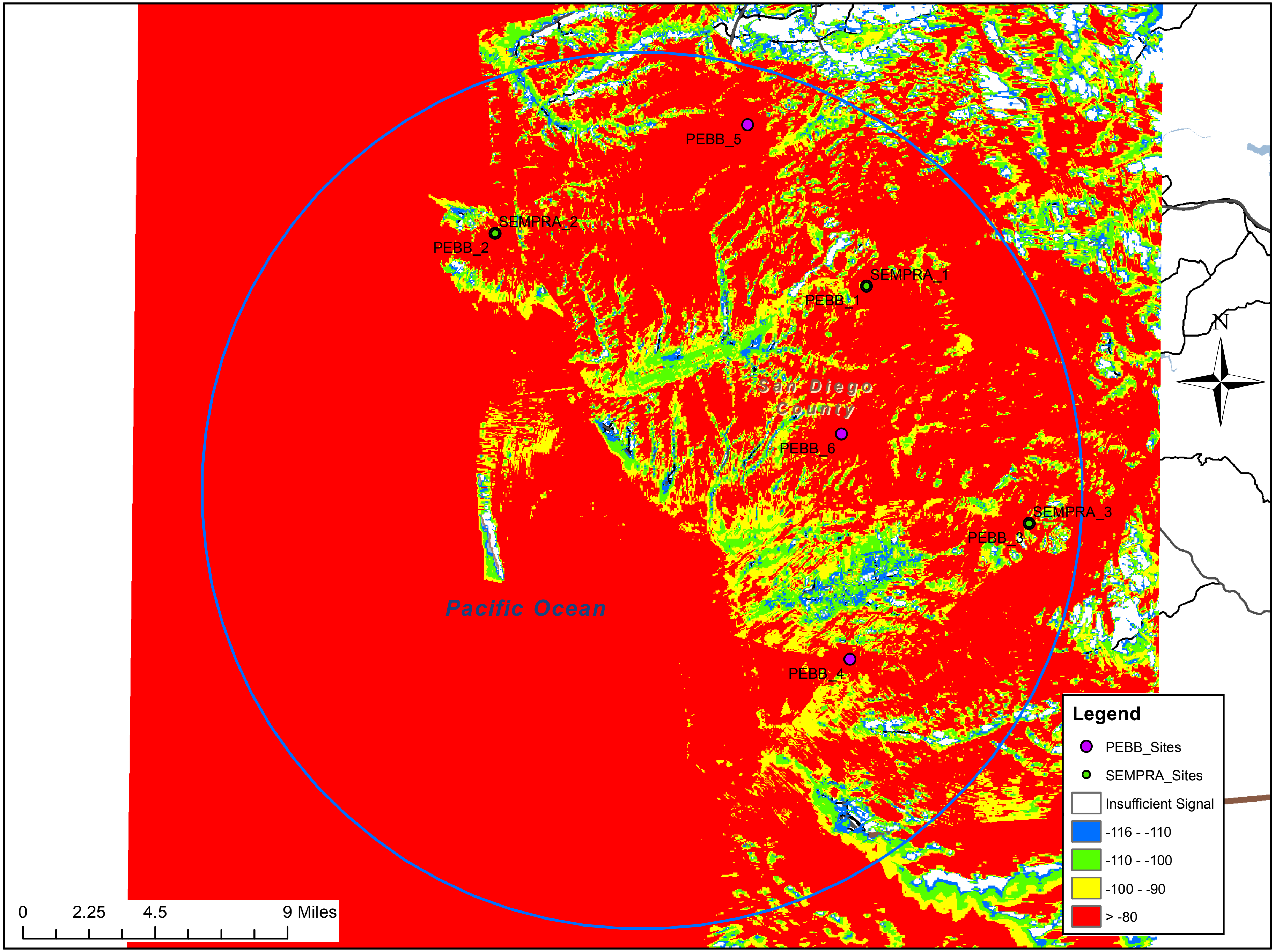


Pericle Communications Company

May 3, 2017

Appendix A.3 - Coverage & Interference Plots for San Diego, CA

PEBB Heatmap



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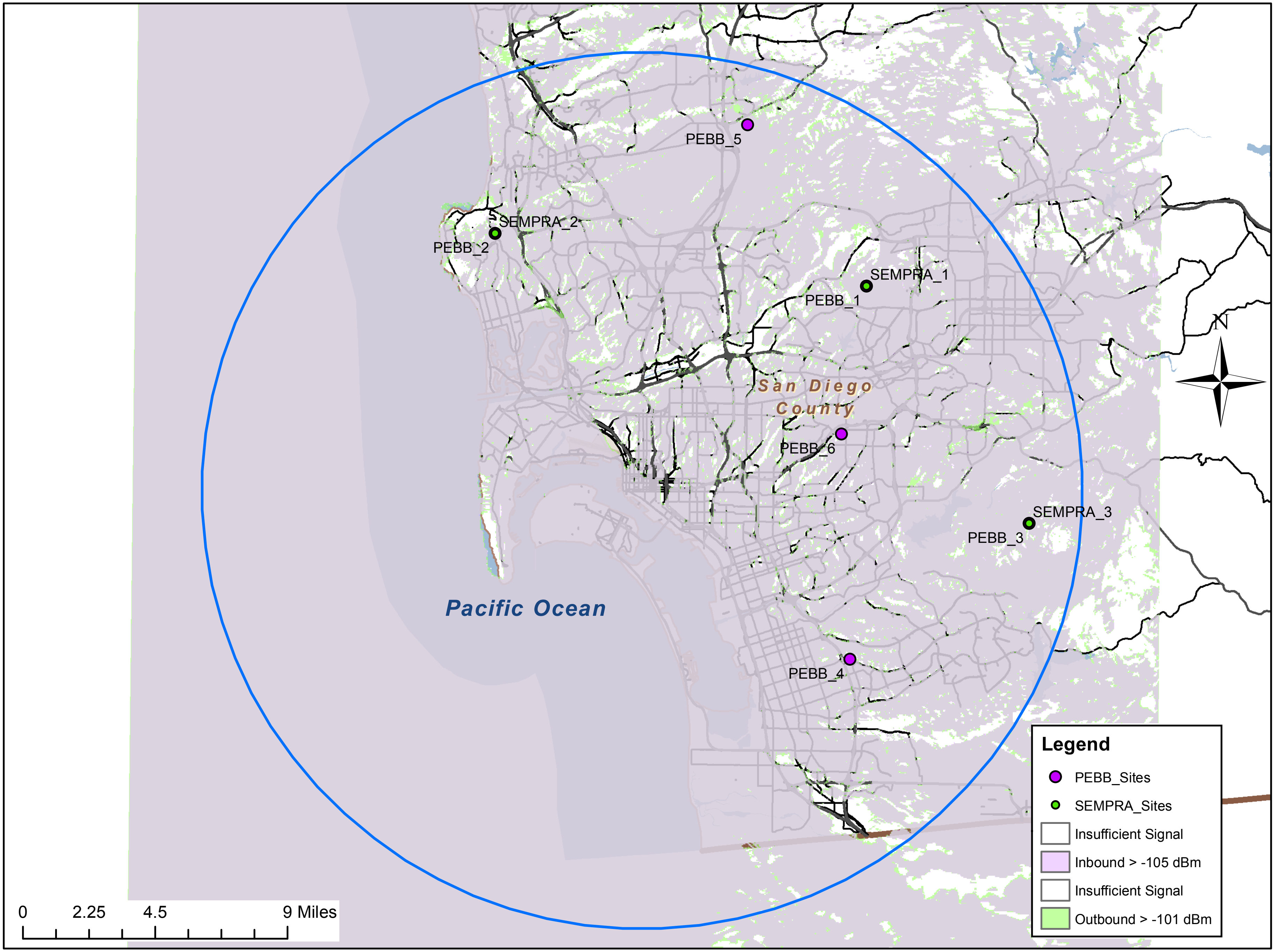
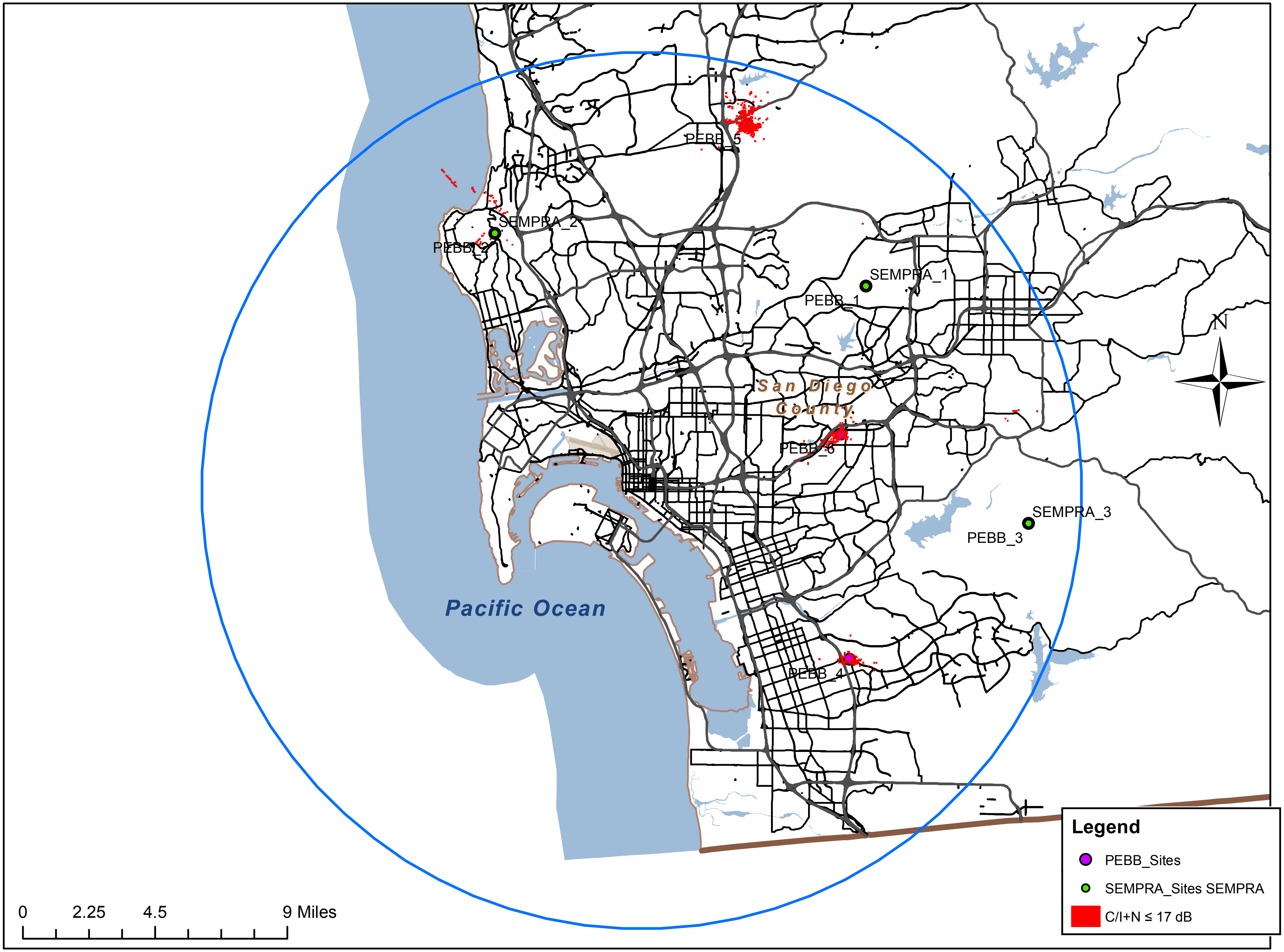
SEMPRA Coverage Map



Pericle Communications Company

May 3, 2017

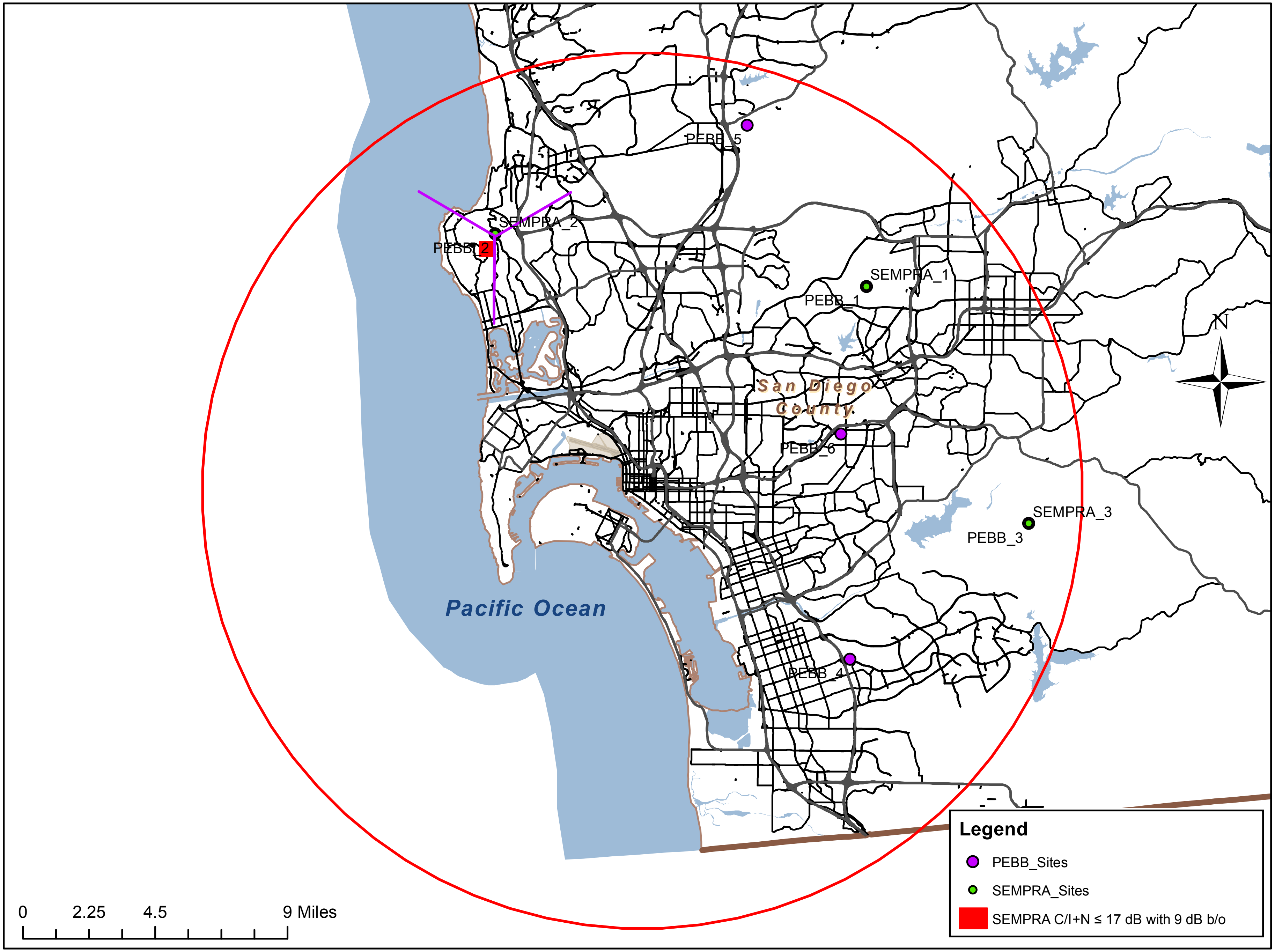
SEMPRA Downlink Interference



Pericle Communications Company

May 3, 2017

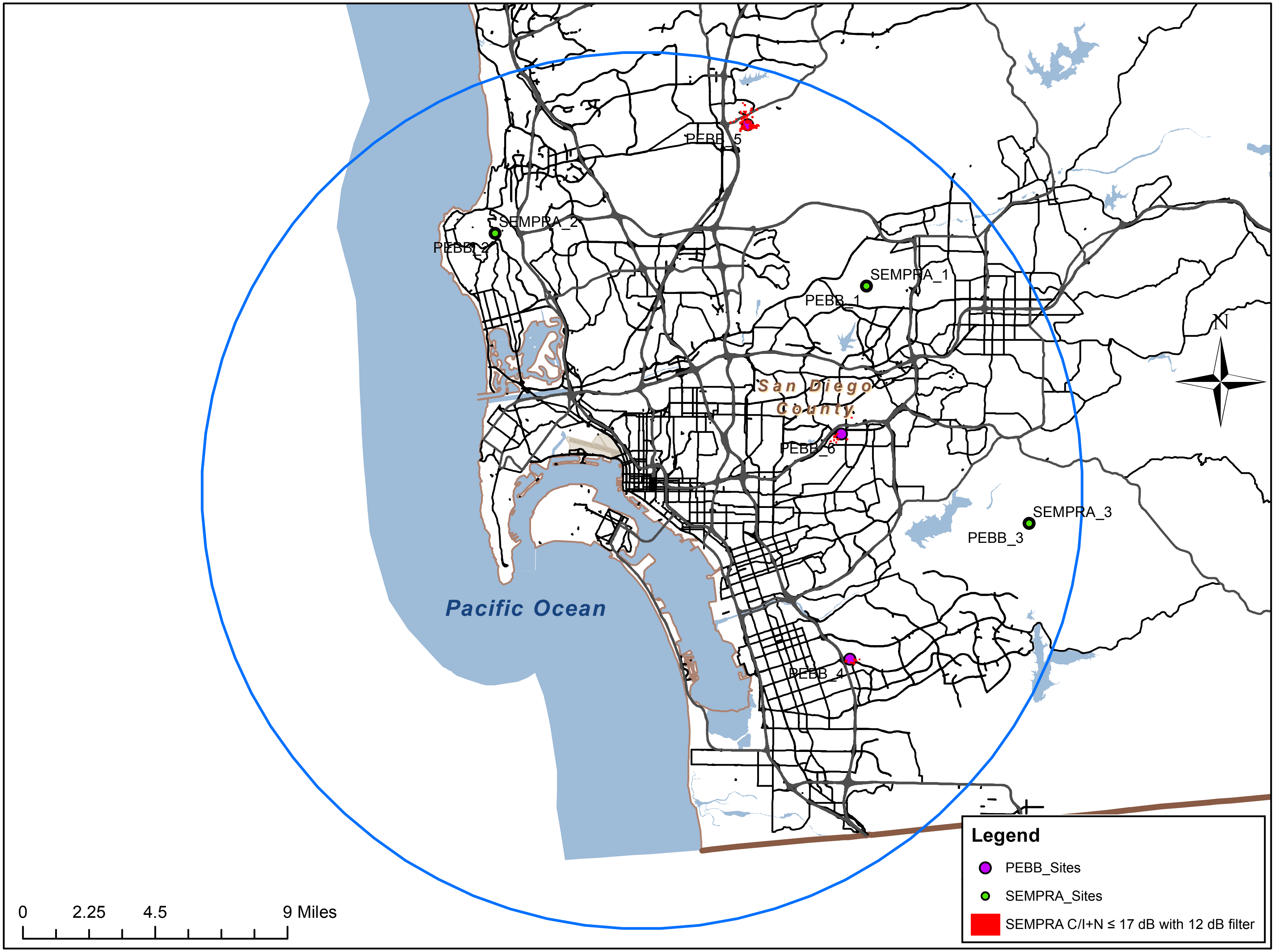
SEMPRA Uplink Interference (3 LTE Users)



Pericle Communications Company

May 3, 2017

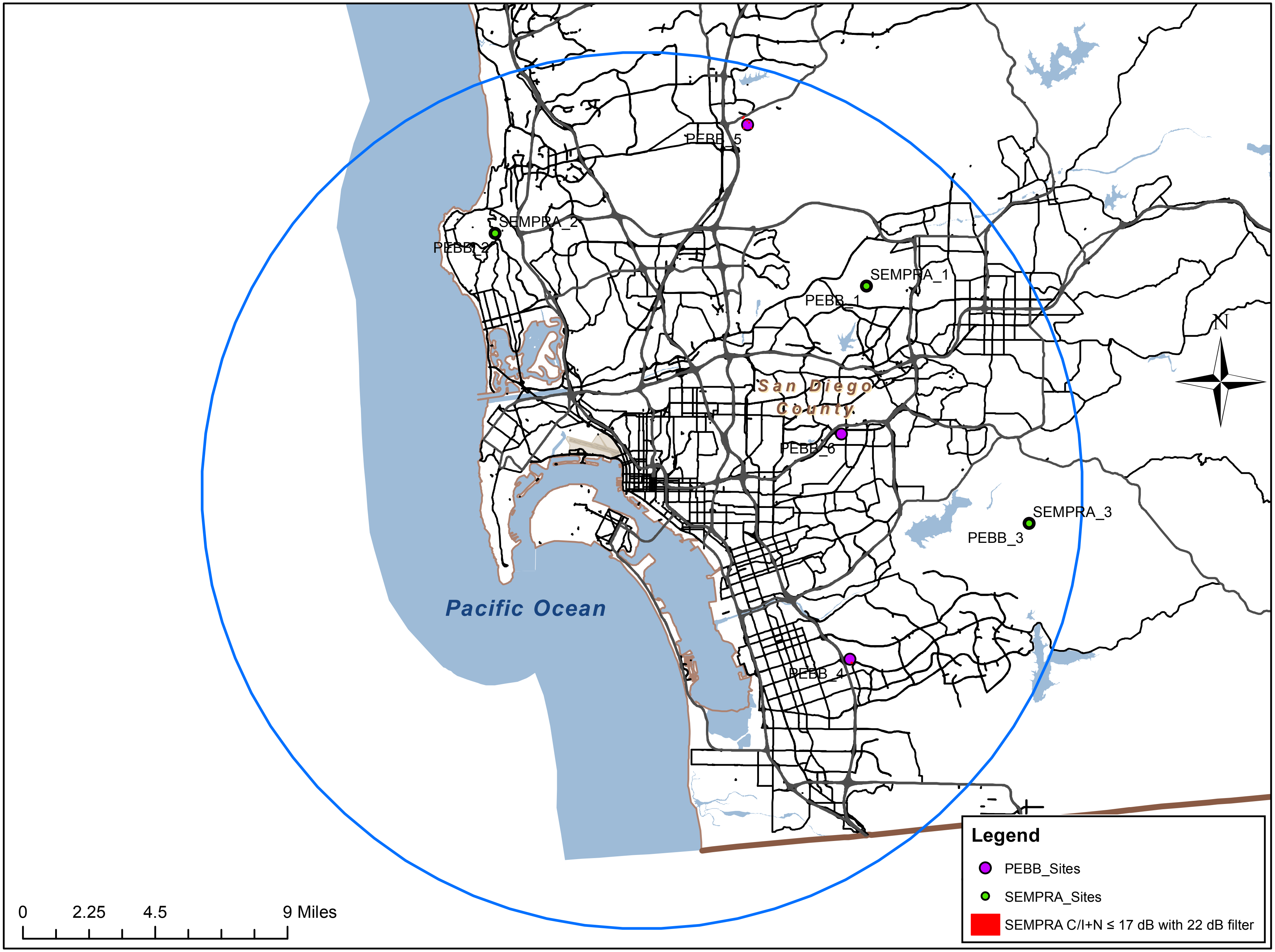
SEMPRA Downlink Interference with 12 dB Filter



Pericle Communications Company

May 3, 2017

SEMPRA Downlink Interference with 22 dB Filter



Pericle Communications Company

May 3, 2017

Appendix B - 900 MHz Subscriber Radio Test Plan

September 29, 2017

1.0 Purpose

The primary purpose of these tests is to measure the effect of an adjacent 3 MHz LTE carrier on the receiver performance of a narrowband 900 MHz subscriber radio. The strong LTE carrier will result in spectral regrowth (a form of intermodulation) in the victim receiver. Other effects such as blocking may also occur. Because we are interested solely in the receiver performance, it is important to employ a signal generator with a pristine LTE signal (low transmitter spectral regrowth and phase noise) to eliminate OOBE as a cause of receiver desense.

We will refer to the test as the Strong Signal Interference (SSI) rejection test. SSI rejection is defined as the difference in dB between the amplitude of the LTE carrier and the amplitude of the desired signal required to achieve 12 dB SINAD. The *desense* is derived from the interference rejection and is the difference in dB between this desired signal level and the 12 dB SINAD sensitivity of the receiver in the absence of interference. Three typical 900 MHz radios will measured:

Motorola XPR-6580
Motorola XPR-7580
Motorola APX-4000

Three radios of each model number will be measured to preclude drawing general conclusions from outliers. In addition to the strong signal interference rejection, other industry standard tests will be conducted on each radio in accordance with TIA-603-D:

- 12 dB SINAD sensitivity
- Intermodulation rejection
- Blocking rejection

2.0 Subscriber Setup and Test Equipment Setup

The test equipment setup is shown in Figure 1. Two signals shall be generated and fed to the receiver antenna test port through a four port combiner. The combiner shall be selected for its linearity and port-to-port isolation and shall be tested for linearity. Unused ports shall be terminated. The first signal is the LTE carrier which emulates the interfering signal. The second signal is the narrowband subscriber desired signal.

The LTE carrier is generated by a Rhode & Schwarz model SMW200A Vector Signal Generator (VSG). The VSG shall be configured for optimized ACP (narrow) to reduce OOBE. Nominal bandwidth shall be 3 MHz which results in 2.7 MHz occupied bandwidth (15 resource blocks, 12 subcarriers per resource block, 180 subcarriers). A cavity filter shall be used as necessary to reduce OOBE to well below the level where receiver effects occur.

The desired signal will be generated by an HP 8920A service monitor. The desired signal shall be a 900 MHz carrier frequency modulated with a 1 kHz tone and 1.5 kHz deviation (60% of max). SINAD shall be measured using the 8920A audio analyzer with a 3 kHz low pass filter.

All coaxial cables, combiners and other test components shall be swept for insertion loss and recorded to adjust signal generator amplitudes to correct for insertion loss. Measurements shall be collected over six frequencies:

Channel No.	RX Frequency
1	935.0125 MHz
40	935.5000
80	936.0000
120	936.5000
148	936.8500
159	936.9875

3.0 Method of Test

3.1 Receiver Sensitivity. Test in accordance with TIA-603-D, paragraph 2.1.4.

3.2 Receiver Intermodulation Rejection. Test in accordance with TIA-603-D, paragraph 2.1.9 for 12.5 kHz channel spacing.

3.3 Blocking. Test in accordance with TIA-603-D, paragraph 2.1.21.

3.4 Strong Signal Interference Rejection. Follow the test plan described in Attachment A.

4.0 Presentation of Data

Record the measurement data in an Excel spreadsheet. Plot the SSI rejection as a function of interfering signal level from -40 to -10 dBm in 5 dB steps.

Attachment A - Strong Signal Interference Rejection Test Procedures

1.0 Introduction

The purpose of this test is to measure the ability of the 900 MHz subscriber radio receiver to reject receiver-induced strong signal interference which might be spectral regrowth, phase noise or blocking from a single LTE carrier. The receiver will be treated as a "black box" and the precise interference mechanisms occurring in the receiver are not important to the results. Because we are interested solely in the performance of the receiver as opposed to the transmitter, it is important that a pristine LTE carrier be used with OOBE well below the level where receiver effects occur.

2.0 Definitions

2.1 The standard input signal is a frequency modulated carrier using a 1 kHz tone and 60% of maximum deviation (e.g., 1.5 kHz deviation for 2.5 kHz max deviation on a 12.5 kHz channel).

2.2 The reference sensitivity, PREF, is the received signal amplitude in dBm required to achieve 12 dB SINAD.

2.3 SSI Rejection. Strong signal interference rejection is defined the ability of a receiver to prevent an undesired input signal from causing degradation to the reception of a desired signal. In this case, a single LTE carrier is used to emulate an interfering signal. It is expressed as the ratio (in dB) of the level of the interfering LTE signal to the minimum amplitude of the desired signal required to achieve 12 dB SINAD.

3.0 Characteristics of Test Equipment

The receiver under test is the portable or mobile radio subscriber. This radio should be inspected to ensure it is in proper working order before testing starts. Interfering signals are normally generated by two signal generators but in this case only a single VSG will be used. If phase noise or other OOBE limits the test, a cavity filter should be used at the output of the VSG. A network analyzer or cable/antenna tester is required to accurately measure the insertion loss of all couplers, power combiners and attenuators (if used) in the test circuit. Double-shielded or solid shield coaxial cable is required to minimize unwanted coupling. All test equipment shall have current calibration traceable to NIST.

4.0 Methods of Measurement

4.1 Setup. Configure the test equipment as shown in Figure 1. Connect the HP 8920A (desired signal) and SMW200A (LTE interfering signal) through a four port combiner with the output connected to the subscriber radio antenna port (or test antenna port). Connect the audio output of the subscriber radio to the audio input of the 8920A (SINAD meter). Configure the SMW200A to generate a nominal 3 MHz wide LTE signal centered on 938.5 MHz, E-TM1.1 Base Station Conformance Waveform and optimized for ACP (narrow). Measure and record the out-of-band emissions in a 8.5 kHz equivalent noise bandwidth (IF bandwidth of subscriber) at each test frequency. Be aware that the spectrum analyzer phase noise and sensitivity may prevent accurate measurement of weak OOBE. If necessary, connect a cavity filter tuned to pass 937.15-939.85 MHz with at least 12 dB rejection at 937 MHz between the SMW200A and the power combiner. Use the Network Analyzer to measure insertion loss of test components and calibrate for cable, cavity filter (if used) and combiner loss.

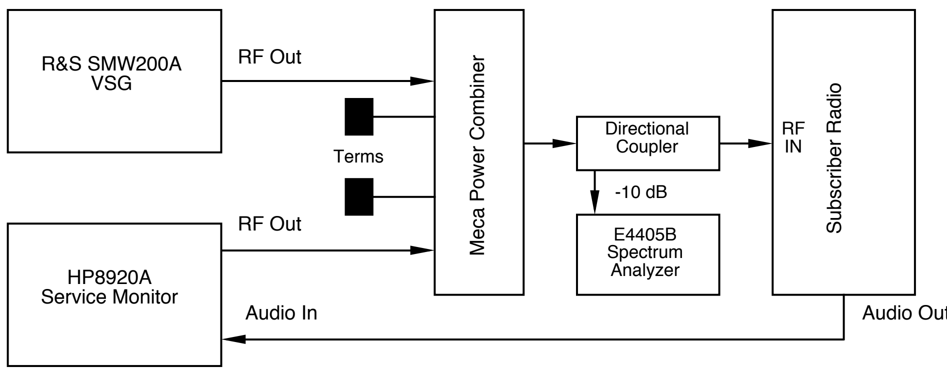


Figure 1 - Test Equipment Setup

Verify that the subscriber radios under test are configured (via codeplug) properly for this test, including setting the RF AGC feature to “STD” (XPR-6580 and APX-4000 only). The radio should be configured for conventional duplex operation, analog FM, maximum deviation of 2.5 kHz, no audio squelch, carrier squelch set below the best case sensitivity.

4.2 Strong Signal Interference Rejection.

4.2.1 Set the LTE signal amplitude to -40 dBm as measured at the antenna port. This is the level of the interfering signal.

4.2.2 Configure the HP 8920A to generate a desired signal on test frequency #1. This signal shall be frequency modulated with a 1 kHz tone and 1.5 kHz deviation.

4.2.3 Increase the desired signal amplitude on the HP 8920A until the SINAD is 12 dB. The strong signal IM rejection is the difference (in dB) between the interfering level and the desired signal level. Note that, depending on the rejection ability of the receiver and the sensitivity of the receiver, the desired signal level may be equal to the receiver sensitivity.

4.2.4 Repeat the above steps for LTE interferer amplitudes of -35, -30, -25, -20, -15, and -10 dBm.

4.2.5 For each subscriber radio, plot SSI rejection versus interferer amplitude from -40 to -10 dBm in 5 dB steps.

4.2.6 Repeat above for all test frequencies (six total).

4.3 Strong Signal IM (SSIM) Rejection (emulation of 800 MHz Scenario at 900 MHz).

4.3.1 Set the 1.25 MHz CDMA and 5 MHz LTE signal amplitude each to -40 dBm as measured at the antenna port. This is the level of the interfering signals. Configure the CDMA waveform to the cdma2000 downlink. (The SMW200A can transmit the two waveforms simultaneously.) Set the CDMA center frequency to 937.8375 MHz and the LTE center frequency to 941.2375 MHz. See Figure 2.

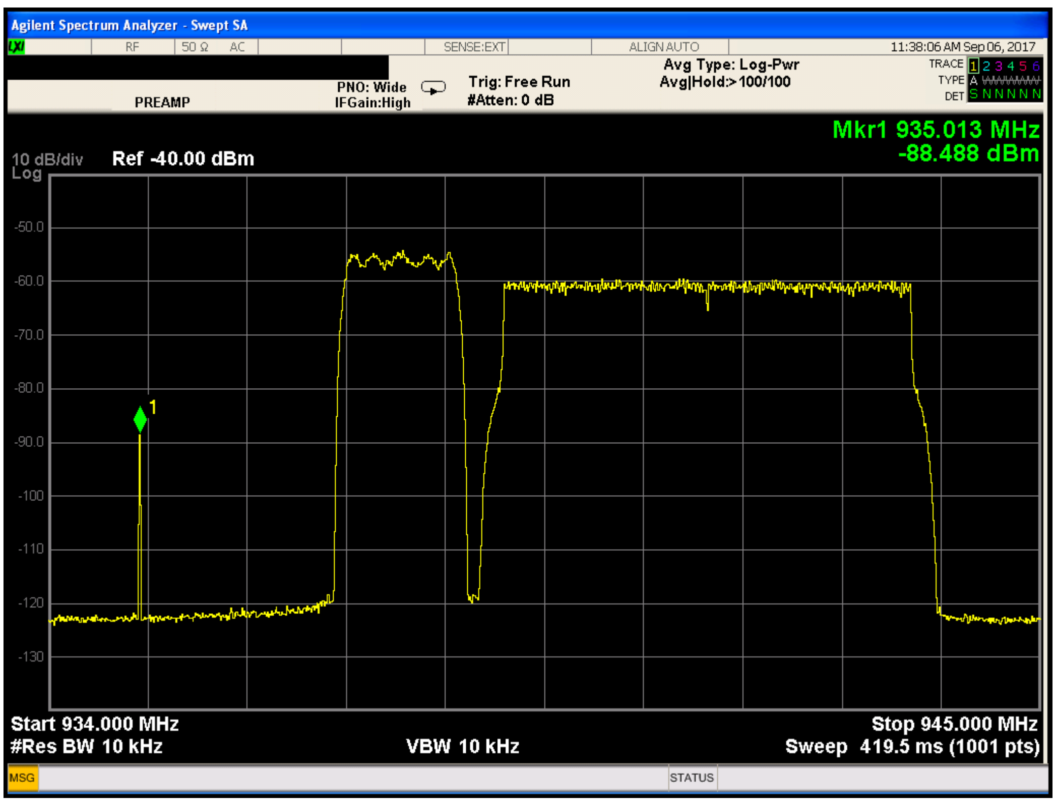


Figure 2 - Spectrum Analyzer Trace of 800 MHz Scenario at 900 MHz

4.3.2 Configure the HP 8920A to generate a desired signal on 935.0125 MHz. This signal shall be frequency modulated with a 1 kHz tone and 1.5 kHz deviation.

4.3.3 Increase the desired signal amplitude on the HP 8920A until the SINAD is 12 dB. The strong signal IM rejection is the difference (in dB) between the interfering level and the desired signal level. Note that, depending on the rejection ability of the receiver and the sensitivity of the receiver, the desired signal level may be equal to the receiver sensitivity.

4.3.4 Repeat the above steps for CDMA and LTE interferer amplitudes of -35, -30, -25, -20, -15, and -10 dBm.

4.3.5 For each subscriber radio, plot SSIM rejection versus interferer amplitude from -40 to -10 dBm in 5 dB steps.

4.4 Test Equipment Required.

- Rhode & Schwarz SMW200A VSG, S/N 101086, Option B22 (low phase noise)
- Agilent E4433B VSG, S/N US40051614
- HP 8920A Service Monitor, S/N 3550A07553
- Agilent 5071B Network Analyzer, S/N MY42403489
- Agilent E4405B Spectrum Analyzer, S/N US40520780
- MECA four port combiner, Model #804-4-1.500V
- Narda 10 dB Directional Coupler, Model 3001.1, S/N 32123
- Tensolite test coaxial cables

Record S/N and calibration data for each instrument.

- END OF TEST PLAN -

Appendix C - Manufacturer Data Sheets

Bittium

Bittium Tough Mobile

Secure and Strong LTE Smartphone

The **Bittium Tough Mobile** smartphone is designed and built for Security, Public Safety, and other professional markets. The sleek and rugged Bittium Tough Mobile provides superior security and compliance with carrier-grade feature requirements. These include hardware based security, a powerful quad-core LTE-Advanced processor, Android 5.1, a configurable button for PTT, military grade mechanics, and support for LTE Band 14. Bittium can also provide product customization, solution integration, and other services to address unique customer requirements.

Secure

World's most secure mobile platform with hardened OS. Options for customer-specific security features.

Powerful

2.3GHz quad-core processor provides performance for the most demanding applications with low power consumption.

Global

9 LTE frequencies in a single device configuration provides global 4G connectivity.

Robust

Industrial design and mechanical packaging to meet high environmental and durability demands. IP67 water and dust resistance, MIL-STD-810G shock resistance.

Proven

Base platform rigorously tested and validated by leading commercial wireless carriers ensuring interoperability and feature compatibility across various network configurations.

FOR MORE INFORMATION, PLEASE CONTACT:

sales@bittium.com

Bittium Tough Mobile
Specifications

Qualcomm Snapdragon 801

- Quad–core Krait CPU 2.3GHz
- Adreno 330 3D graphics accelerator
- Hexagon QDSP 600 MHz

Operating System

- Operating system: Android™ 5.1 Lollipop
- Available with or without Google Mobile Services

Memory

- 2GB LPDDR3 RAM
- 16GB eMMC Mass Storage
- Micro SD expansion slot

Security

- Secure boot with HW-enabled integrity
- Runtime integrity
- Application permission firewall
- Secure data storage for user credentials and encryption keys
- Encrypted mass memory
- Tampering detection
- PGP encrypted email
- FIPS 140-2 compliant HW cryptography
- Secure Suite (optional)
  - Mobile VPN
  - Device management
  - Remote attestation
  - Enterprise app library
  - Log server
  - Secure push service

Display

- 5" Full HD (1080*1920) LCD
- Glove-usable capacitive touch, functional also in wet conditions.

Interfaces

- USB3.0 with fast charging
- Wireless display (Miracast compliant)
- Dual-SIM slots

Battery

- **2420mAh Li-Ion**

Wireless Connectivity

LTE

- 3GPP rel10 (LTE Advanced)
- FDD Cat4, DL 150 Mbit/s, UL 50 Mbit/s
- IMS, VoLTE-ready
- Band configuration:
- US: B2 (1900), B4 (1700), B5 (850), B17 (700), B13 (700), B14 (700)
- EU: B3 (1800), B7 (2600), B20 (800)
- Carrier Aggregation: supported

UMTS/HSPA

- 3GPP rel8, HSPA+, DL 42 Mbit/s, UL 5.76 Mbit/s
- Band configuration:
- US: B2 (1900), B4 (1700), B5 (850)
- EU/APAC: B1 (2100), B8 (900)

GSM/GPRS/EDGE

- 850/900/1800/1900 MHz

Other Radios

- Wi-Fi 802.11 a/b/g/n/ac
- BT 4.0
- NFC

Push-to-talk (PTT)

- Configurable button for PTT, camera, etc.

Sensors

- 3D Gyroscope
- 3D Accelerometer
- 3D Magnetometer
- Proximity Sensor
- Ambient Light Sensor
- Barometer

Imaging and Video

- 8 MP with Autofocus and LED Flash
- 2 MP for front facing applications
- Full HD video capture and playback

Audio

- High-performance speakers
- Multi-microphone active noise cancelling
- Earpiece and microphone
- 3.5mm headset connector

Positioning

- aGPS/Glonass
- iZat™ positioning framework

Mechanical

- Size 141mm x 75,5mm x 13,5mm
- Weight 180g
- IP67 water and dust resistant
- MIL-STD-810G shock resistant

Operating range

- -20°C…+60°C

Certifications

- FCC, CE
- Finnish national approval for RESTRICTED classification level (with Secure Suite)

Bittium - 22722 29th Dr. SE, Suite 100, Bothell, WA 98021 – Tel. +1 469 233 2231 - **www.bittium.com**

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Bandpass Filter for Pacific Datavision

Tel: 201-342-3338 Fax: 201-342-3339 www.cciproducts.com

General Information

Communication Components, Inc. Bandpass filter allows a 2.8 MHz band in the 937-940 MHz Band pass, while rejecting signals within 100 KHz of the passband.

The CCI Bandpass filter provides performance for the passband with low insertion loss, low Intermodulation, and high power handling. Excellent return loss delivers the best match to the antennas and base station, saving precious transmit power. The Banpass filter is the ideal solution for encompassing a 3MHz LTE carrier and rejecting all spectrum regrowth

Model
BP-937-940-I

Contents:

Features:

- Low Loss
- Good Rejection
- Good IM
- High reliability

Technical Description

The bandpass filter consists of multiple cavity resonators utilizing high dielectric ceramics to achieve 25dB rejection within 100 KHz of the pass band. Extensive temperature compensation is employed to insure frequency stability over the specified temperature range.

Bandpass Filter Electrical & Mechanical Specifications

Description	Typical Specifications
Electrical Specifications	
Passband	2.8 MHz Wide (centered within 937-940 MHz)
Insertion loss (1.6 MHz Bandwidth)	1.0 dB maximum
Insertion loss (2.6 MHz Bandwidth)	1.5 dB maximum
Return Loss	20 dB Minimum
Rejection (within 100 KHz of Passband)	25 dB minimum
Power Handling	200 Watts Average, 3KW peak
IM3	-155 dBc min., 2 x 20 W carriers
Common Specifications	
Impedance	50 Ohms
Mechanical Specifications	
Connectors	7-16 DIN-Female (Long Neck) x 2
Dimensions (Bracket & Connectors not included)	18” x 7” x 4” (457.2 x 177.8 x 101.6 mm) - Single Unit
Weight	Approximately 40 LBS
Finish	Epoxy Powder Coat
MTBF	500,000 Hours Minimum
Mounting	19” Rack Mount
Environmental Specifications	
Operating Temperature	25°F +/-10°
Environmental Protection	Indoor Rated
Relative Humidity	0– 50%

All specifications are subject to change. The latest specifications are available at www.cciproducts.com

Communication Components Inc.

Tel: 201-342-3338 Fax: 201-342-3339

EXTENDING WIRELESS PERFORMANCE

89 Leuning Street
South Hackensack, NJ 07606

Tel: 201-342-3338
Fax: 201-342-3339
WWW.CCIPRODUCTS.COM

Ordering Information:

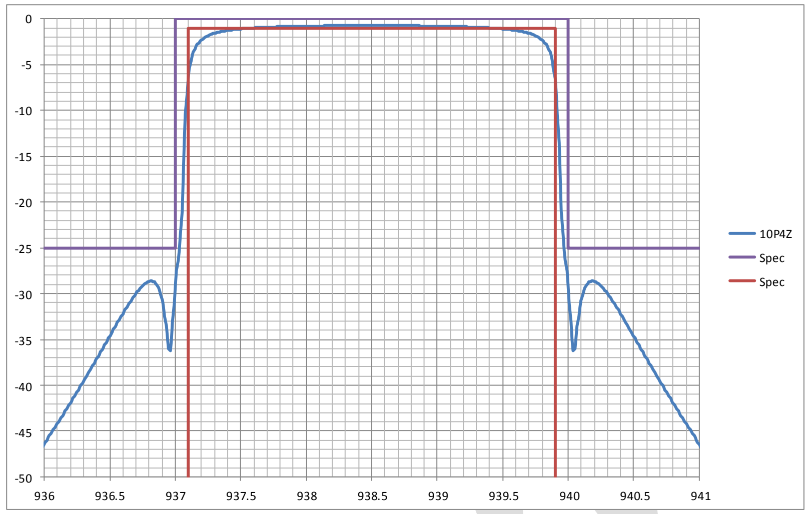
- **Model BP-937-940-I**
  (Single Unit)

Options:

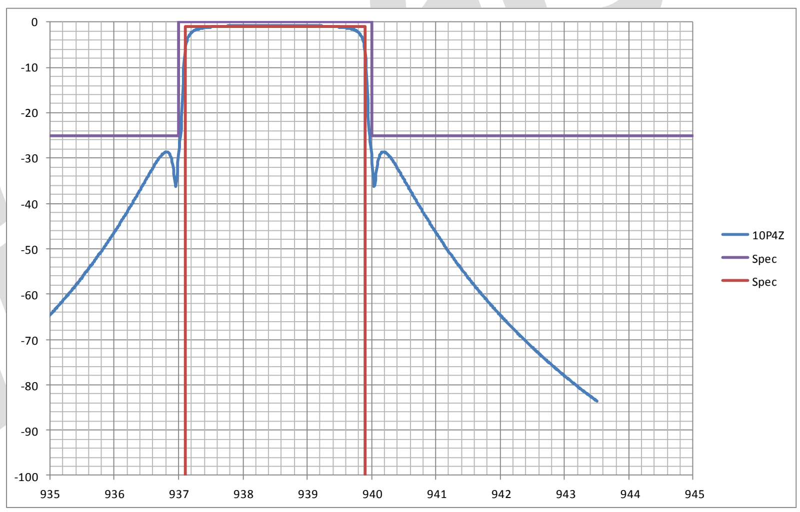
- **19” Mounting Tray**

Accessories:

Bandpass Filter Narrowband and Wideband Response Characteristics



Narrowband Characteristics



Wideband Characteristics

Bandpass Unit Outline Drawing

Dimensions in inches (mm)

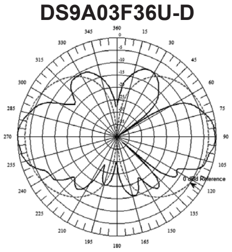
dbSpectra

900 MHz Omni Antennas (890-960 MHz)

		890-960 MHz								
	Model Number	**DS9A03F36U-N** / **DS9A03F36U-D**	**DS9A06F36U-N** / **DS9A06F36U-D**	**DS9A09F36U-N** / **DS9A09F36U-D**	**DS9A10F36U-N** / **DS9A10F36U-D**	**DS9A12F36U-N** / **DS9A12F36U-D**	**DS9A03F36D-N** / **DS9A03F36D-D**	**DS9A06F36D-N** / **DS9A06F36D-D**	**DS9A09F36D-N** / **DS9A09F36D-D**	**DS9A06F36T-N** / **DS9A06F36T-D**
	Input Connector	N(F) / 7/16 DIN	N(F) / 7/16 DIN	N(F) / 7/16 DIN	N(F) / 7/16 DIN	N(F) / 7/16 DIN	N(F) / 7/16 DIN	N(F) / 7/16 DIN	N(F) / 7/16 DIN	N(F) / 7/16 DIN
	Type	Single	Single	Single	Single	Single	Dual	Dual	Dual	Triple
ELECTRICAL	**Bandwidth**, MHz	70	70	70	70	70	70	70	70	70
	Power, Watts	500	500	500	500	500	350	350	350	250
	Gain, dBd	3	6	9	10	12	3	6	9	6
	Horizontal Beamwidth, degrees	360	360	360	360	360	360	360	360	360
	Vertical Beamwidth, degrees	30	16	8	6	3	30	16	8	16
	Beam Tilt, degrees	0	0	0	0	0	0	0	0	0
	Isolation (minimum), dB	N/A	N/A	N/A	N/A	N/A	40	40	45	40
MECHANICAL	**Number of Connectors**	1	1	1	1	1	2	2	2	3
	Flat Plate Area, ft²(m²)	0.24 (0.02)	1.28 (0.12)	2.26 (0.21)	3.25 (0.3)	4.33 (0.4)	1.38 (0.13)	2.27 (0.21)	3.83 (0.36)	3.47 (032)
	Lateral Windload Thrust, lbf(N)	11 (48)	48 (214)	85 (377)	122 (543)	163 (723)	31 (139)	85 (374)	144 (641)	87 (385)
	Survival Wind Speed									
	without ice, mph(kph)	437 (703)	250 (402)	150 (241)	105 (169)	75 (121)	379 (610)	150 (241)	90 (145)	136 (219)
	with 0.5" radial ice, mph(kph)	319 (513)	225 (362)	127 (204)	88 (142)	60 (97)	294 (473)	125 (201)	75 (121)	106 (171)
	Mounting Hardware included	DSH2V3R	DSH2V3R	DSH3V3R	DSH3V3N	DSH3V3N	DSH2V3R	DSH3V3R	DSH3V3N	DSH3V3N
DIMENSIONS	**Length**, ft(m)	2.9 (0.9)	6.7 (2)	11.4 (3.5)	16.3 (5)	21.8 (6.6)	8 (2.4)	11.4 (3.5)	19.2 (5.9)	15.3 (4.7)
	Radome O.D., in(cm)	2 (5.1)	3 (7.6)	3 (7.6)	3 (7.6)	3 (7.6)	3 (7.6)	3 (7.6)	3 (7.6)	3 (7.6)
	Mast O.D., in(cm)	2.5 (6.4)	2.5 (6.4)	2.5 (6.4)	2.5 (6.4)	2.5 (6.4)	2.5 (6.4)	2.5 (6.4)	2.5 (6.4)	3.2 (8.13)
	Net Weight w/o bracket, lb(kg)	5.5 (2.5)	18 (8.2)	30 (13.6)	45 (20.4)	52 (23.6)	21 (9.5)	31 (14.1)	50 (22.7)	40 (18.1)
	Shipping Weight, lb(kg)	9.6 (4.4)	28 (12.7)	60 (27.2)	75 (34)	82 (37.2)	51 (23.1)	61 (27.7)	80 (36.3)	50 (22.7)

VERTICAL PATTERNS

DS9A03F36U-N
DS9A03F36U-D



DS9A06F36U-N
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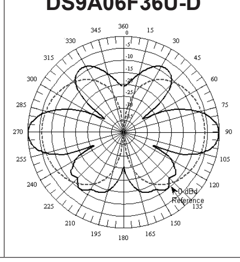

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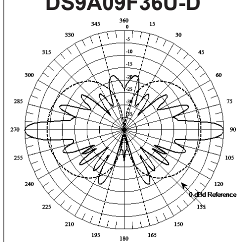

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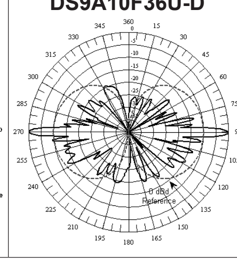

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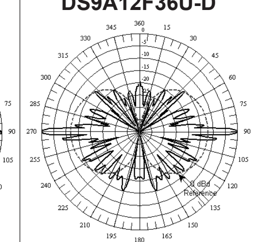

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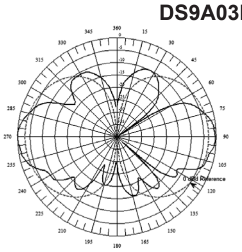
DS9A03F36D-D



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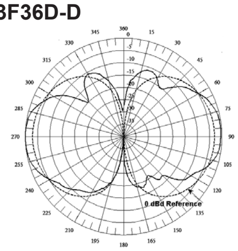

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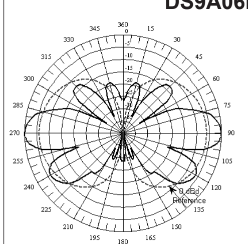
DS9A06F36D-N
DS9A06F36D-D



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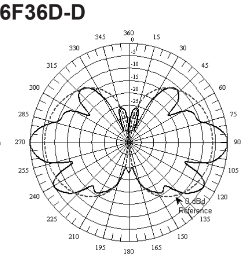

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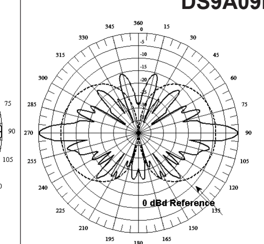
DS9A09F36D-N
DS9A09F36D-D



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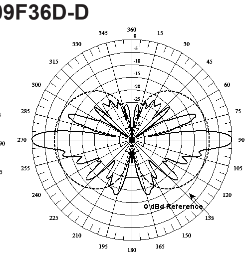


Bottom

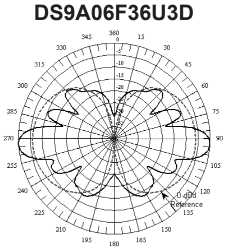
dbSpectra

900 MHz Omni Antennas (890-960 MHz)

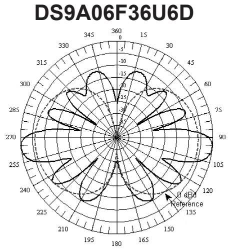
		890-960 MHz					
	Model Number	**DS9A06F36U3N**	**DS9A06F36U3D**	**DS9A06F36U6N**	**DS9A06F36U6D**	**DS9A10F36U3N**	**DS9A10F36U3D**
	Input Connector	N(F)	7/16 DIN	N(F)	7/16 DIN	N(F)	7/16 DIN
	Type	Beamtilt		Beamtilt		Beamtilt	
ELECTRICAL	**Bandwidth**, MHz	70		70		70	
	Power, Watts	500		500		500	
	Gain, dBd	6		6		10	
	Horizontal Beamwidth, degrees	360		360		360	
	Vertical Beamwidth, degrees	16		16		6	
	Beam Tilt, degrees	3 Down		6 Down		3 Down	
	Isolation (minimum), dB	N/A		N/A		N/A	
MECHANICAL	**Number of Connectors**	1		1		1	
	Flat Plate Area, ft²(m²)	1.28 (0.12)		1.28 (0.12)		2.5 (0.23)	
	Lateral Windload Thrust, lbf(N)	48 (214)		48 (214)		122 (543)	
	Survival Wind Speed						
	without ice, mph(kph)	250 (402)		250 (402)		105 (169)	
	with 0.5" radial ice, mph(kph)	225 (362)		225 (362)		88 (142)	
	Mounting Hardware included	DSH2V3R		DSH2V3R		DSH3V3N	
DIMENSIONS	**Length**, ft(m)	6.7 (2)		6.7 (2)		16.3 (5)	
	Radome O.D., in(cm)	3 (7.6)		3 (7.6)		3 (7.6)	
	Mast O.D., in(cm)	2.5 (6.4)		2.5 (6.4)		2.5 (6.4)	
	Net Weight w/o bracket, lb(kg)	18 (8.2)		18 (8.2)		45 (20.4)	
	Shipping Weight, lb(kg)	28 (12.7)		28 (12.7)		75 (34)	

VERTICAL PATTERNS

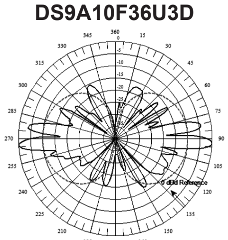
DS9A06F36U3N
DS9A06F36U3D



DS9A06F36U6N
DS9A06F36U6D



DS9A10F36U3N
DS9A10F36U3D



CHHTT65B-C3-3XR

Multiband Antenna, 790–960, 2x 1710–2180 and 2x 2490-2690 MHz, 65° horizontal beamwidth, internal electrical tilt with individual tilt available for the 800-900, 1800-2100 and 2600 MHz bands.

- Uses the 4.3-10 connector which is 40 percent smaller than the 7-16 DIN connector

Electrical Specifications

Frequency Band, MHz	**790–896**	**870–960**	**1710–1880**	**1850–1990**	**1920–2180**	**2490–2690**
Gain, dBi	15.5	15.5	17.3	17.4	17.5	17.1
Beamwidth, Horizontal, degrees	64	63	71	69	66	60
Beamwidth, Vertical, degrees	11.2	10.3	5.6	5.4	5.1	4.3
Beam Tilt, degrees	0–10	0–10	0–8	0–8	0–8	0–8
USLS (First Lobe), dB	15	16	15	16	15	18
Front-to-Back Ratio at 180°, dB	30	30	31	29	25	26
CPR at Boresight, dB	20	19	20	20	18	16
CPR at Sector, dB	9	9	9	9	7	4
Isolation, dB	28	28	28	28	28	28
Isolation, Intersystem, dB	30	30	30	30	30	30
VSWR | Return Loss, dB	1.5 | 14.0	1.5 | 14.0	1.5 | 14.0	1.5 | 14.0	1.5 | 14.0	1.5 | 14.0
PIM, 3rd Order, 2 x 20 W, dBc	-153	-153	-153	-153	-153	-150
Input Power per Port, maximum, watts	350	350	300	300	300	250
Polarization	±45°	±45°	±45°	±45°	±45°	±45°
Impedance	50 ohm	50 ohm	50 ohm	50 ohm	50 ohm	50 ohm

Electrical Specifications, BASTA*

Frequency Band, MHz	**790–896**	**870–960**	**1710–1880**	**1850–1990**	**1920–2180**	**2490–2690**
Gain by all Beam Tilts, average, dBi	15.0	15.1	17.0	17.1	17.1	17.1
Gain by all Beam Tilts Tolerance, dB	±0.4	±0.3	±0.3	±0.3	±0.3	±0.6
Gain by Beam Tilt, average, dBi	0 ° | 15.0 5 ° | 15.1 10 ° | 15.0	0 ° | 15.0 5 ° | 15.1 10 ° | 15.0	0 ° | 16.8 4 ° | 17.0 8 ° | 17.0	0 ° | 17.0 4 ° | 17.1 8 ° | 17.1	0 ° | 17.0 4 ° | 17.1 8 ° | 17.1	0 ° | 17.1 4 ° | 17.2 8 ° | 17.0
Beamwidth, Horizontal Tolerance, degrees	±2.5	±1.8	±3.2	±2.7	±5	±6.6
Beamwidth, Vertical Tolerance, degrees	±0.8	±0.6	±0.2	±0.2	±0.4	±0.3
USLS, beampeak to 20° above beampeak, dB	16	17	16	17	16	19
Front-to-Back Total Power at 180° ± 30°, dB	24	26	26	25	23	23
CPR at Boresight, dB	21	20	22	22	21	16
CPR at Sector, dB	9	10	13	10	8	5

* CommScope® supports NGMN recommendations on Base Station Antenna Standards (BASTA). To learn more about the benefits of BASTA, download the whitepaper Time to Raise the Bar on BSAs.

Array Layout

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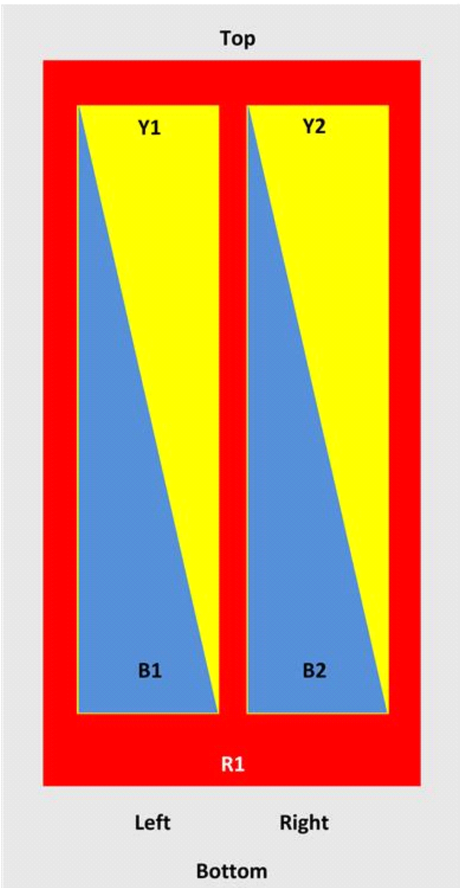
CHHTT65B-C3-3XR



Array	Freq (MHz)	Conns	RET (SRET)	AISG RET UID
R1	790-960	1-2	1	ANxxxxxxxxxxxxxxxxx1
B1	1710-2180	3-4	2	ANxxxxxxxxxxxxxxxxx2
B2	1710-2180	5-6		
Y1	2490-2690	7-8	3	ANxxxxxxxxxxxxxxxxx3
Y2	2490-2690	9-10		

View from the front of the antenna

(Sizes of colored boxes are not true depictions of array sizes)

General Specifications

Operating Frequency Band	1710 – 2180 MHz | 2490 – 2690 MHz | 790 – 960 MHz
Antenna Type	Sector
Band	Multiband
Performance Note	Outdoor usage

Mechanical Specifications

RF Connector Quantity, total	10
RF Connector Quantity, low band	2
RF Connector Quantity, high band	8
RF Connector Interface	4.3-10 Female

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Color	Light gray
Grounding Type	RF connector inner conductor and body grounded to reflector and mounting bracket
Radiator Material	Copper | Low loss circuit board
Radome Material	Fiberglass, UV resistant
Reflector Material	Aluminum
RF Connector Location	Bottom
Wind Loading, frontal	618.0 N @ 150 km/h 138.9 lbf @ 150 km/h
Wind Speed, maximum	241 km/h | 150 mph

Dimensions

Length	1828.0 mm | 72.0 in
Width	301.0 mm | 11.9 in
Depth	181.0 mm | 7.1 in
Net Weight, without mounting kit	20.2 kg | 44.5 lb

Remote Electrical Tilt (RET) Information

Input Voltage	10–30 Vdc
Internal RET	High band (2) | Low band (1)
Power Consumption, idle state, maximum	2.0 W
Power Consumption, normal conditions, maximum	13.0 W
Protocol	3GPP/AISG 2.0 (Single RET)
RET Interface	8-pin DIN Female | 8-pin DIN Male
RET Interface, quantity	1 female | 1 male

Packed Dimensions

Length	1954.0 mm | 76.9 in
Width	409.0 mm | 16.1 in
Depth	299.0 mm | 11.8 in
Shipping Weight	32.8 kg | 72.3 lb

Regulatory Compliance/Certifications

Agency	Classification
RoHS 2011/65/EU	Compliant by Exemption
China RoHS SJ/T 11364-2006	Above Maximum Concentration Value (MCV)
ISO 9001:2008	Designed, manufactured and/or distributed under this quality management system

Included Products

BSAMNT-1 — Wide Profile Antenna Downtilt Mounting Kit for 2.4 - 4.5 in (60 - 115 mm) OD round members. Kit contains one scissor top bracket set and one bottom bracket set.

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* Footnotes

Performance Note	Severe environmental conditions may degrade optimum performance

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dbSpectra

TECHBOOK

Series

RF FILTERS

- RF Filters
- RF Distribution Design
- Antennas
- Understanding PIM
- Intermodulation
- Sensitivity

Introduction

This TECHBOOK will explore the concept of filter design and how it is applied to an RF distribution system. There are several ways filters are used to enhance RF distribution designs. Filters are critical in the design of transmitter and receiver distribution systems. Transmitters must be conditioned to reduce out of band emissions and receivers require additional protection from high level carriers and interference.

What is Selectivity?

To understand filter application the concept of selectivity must be addressed. Selectivity is frequency selective attenuation and will always be related to a frequency or group of frequencies. The frequency component of selectivity is the major difference between selectivity and simple insertion loss. For a filter the insertion loss will be referenced within the passband while selectivity will be characterized outside the passband. Selectivity is also referenced in receiver specifications because receivers must have a significant frequency selectivity to allow reception of one frequency and reject others. The Selectivity of a component is provided by a curve as shown in ***Figure 1***. The selectivity curve shows the frequency response of a filter with frequency as the x-axis and power level as the y-axis.

Definition of design components and terminology

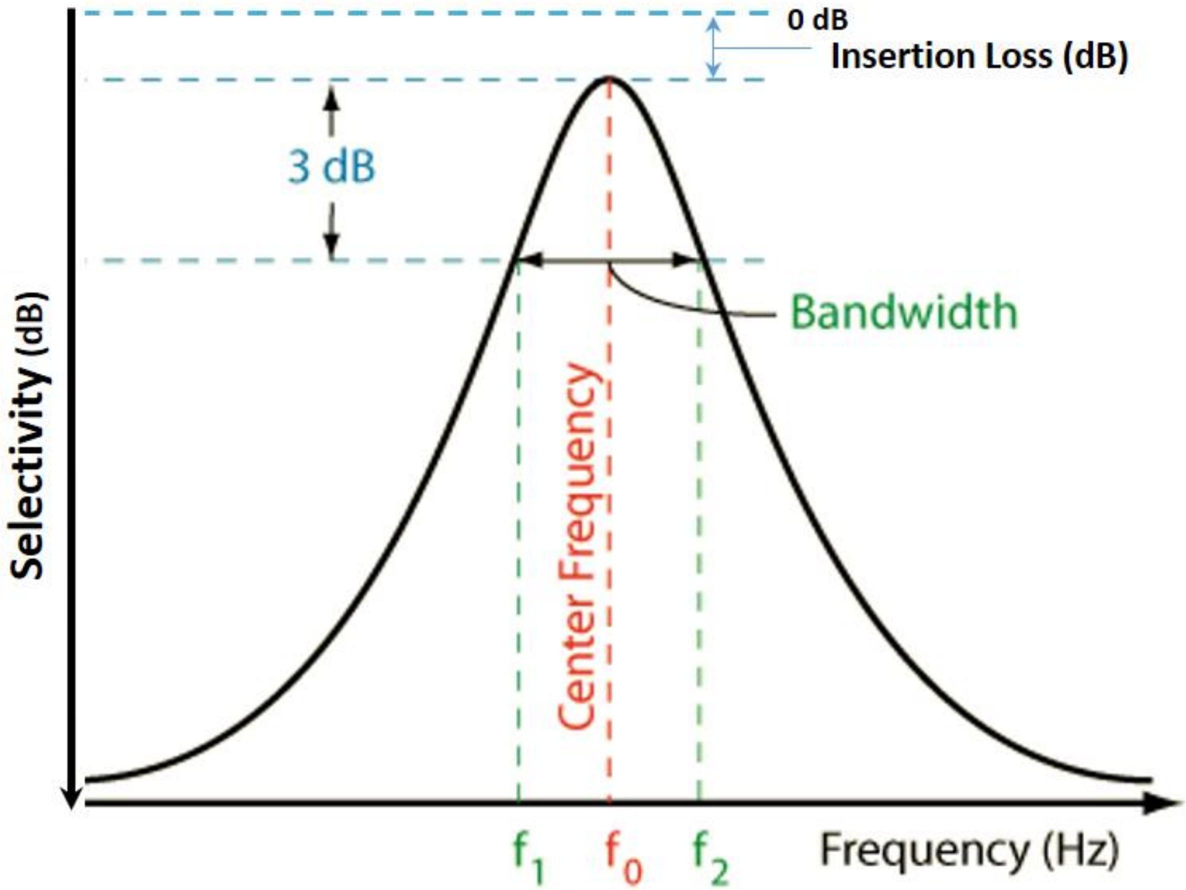

Figure 1: Definition of terminology

Cavity – The legacy building block for a frequency selective device is the cavity. While other devices provide better frequency selectivity, the cavity filter has been used for years and is still found and used on current system designs.

dB – The decibel (dB) is the increment by which the filter selectivity is measured and specified. Th dB a convenient way of showing large increase or decrease in voltage or power levels. It is related to voltage or power by the base 10 logarithm. A typical range for filter measurement is 0 to -120 dB.

Center Frequency – The center frequency is the resonant frequency to which the filter is tuned. The operation of the filter is designed around the center frequency.

Insertion Loss – The insertion loss is the minimum loss of the filter and may be associated with bandpass. The insertion loss point is the tuned operating point.

Bandwidth – The operational bandwidth is generally defined by the frequency separation between the highest frequency and lowest frequency where a 3 dB insertion loss is found. In RF filters the insertion loss may be the bandwidth over which the specified insertion loss exists. The bandwidth may be wide (several MHz) as found in a bandpass filter or sharp (tens of kHz) as characterized by a single cavity. The bandwidth may also be called the passband of the filter.

Q or Quality Factor – Quality factor is used to define the selectivity of a filter with a higher value meaning higher selectivity. Mathematically, Q equals the center frequency divided by the bandwidth.

Filter Types

Bandpass Cavity – The first selectivity component we will examine is a simple band pass cavity ***(Figure 2)***. The bandpass cavity, sometimes called a resonator or cavity resonator, is the basic building block for many complex filter systems. A cavity is a resonant device that is tuned to one frequency or one narrow band of frequencies. At the resonant or tuned frequency, the attenuation will be minimal (normally less than 2 dB depending on the Q of the cavity). As the observed frequency increases or decreases outside the passband the attenuation increases significantly. The increase in attenuation or insertion loss is called selectivity, rejection, or isolation. While the bandpass filter is characterized by steep skirts on either side of the bandpass, the actual bandpass is normally only a few hundred kHz wide and is dependent on the Q of the filter. At the resonant frequency, the Z (impedance) will be 50 ohms and increase as the attenuation increases. Some of the unwanted energy is absorbed by the cavity, but most is reflected back to the source due to impedance mismatch caused by the change in the cavity's impedance. The operation can be considered a frequency controlled variable impedance.

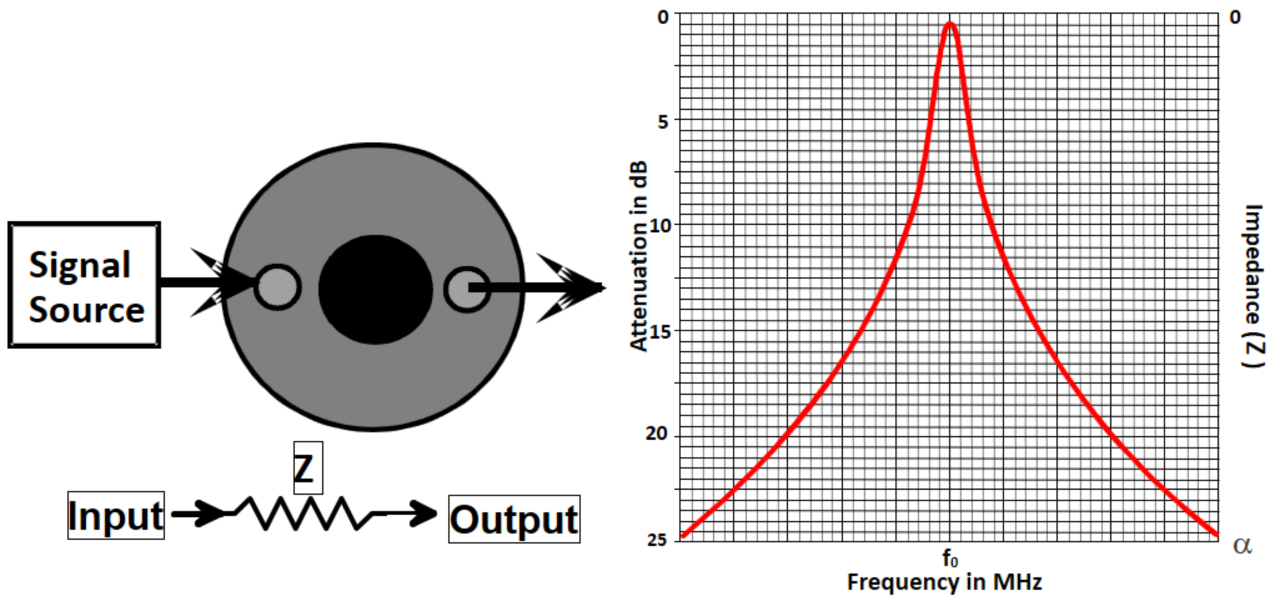

*Figure 2: **Fundamental characteristics of a Bandpass cavity***

A single cavity is limited in the amount of obtainable selectivity. The maximum selectivity achieved is called the depth of selectivity or isolation. As the cavity selectivity is examined further and further from the center frequency the selectivity will flatten and bottom out. A rule of thumb is that a single cavity will obtain 25 – 35 dB of obtainable selectivity before it completely flattens out and stops increasing. The slope of the selectivity or how fast the selectivity increases beyond the bandpass, is controlled by the Q of the filter. As the Q is increased, the selectivity will also increase while the bandwidth decreases. For a specific filter design, increasing the Q will also increase the insertion loss of the filter.

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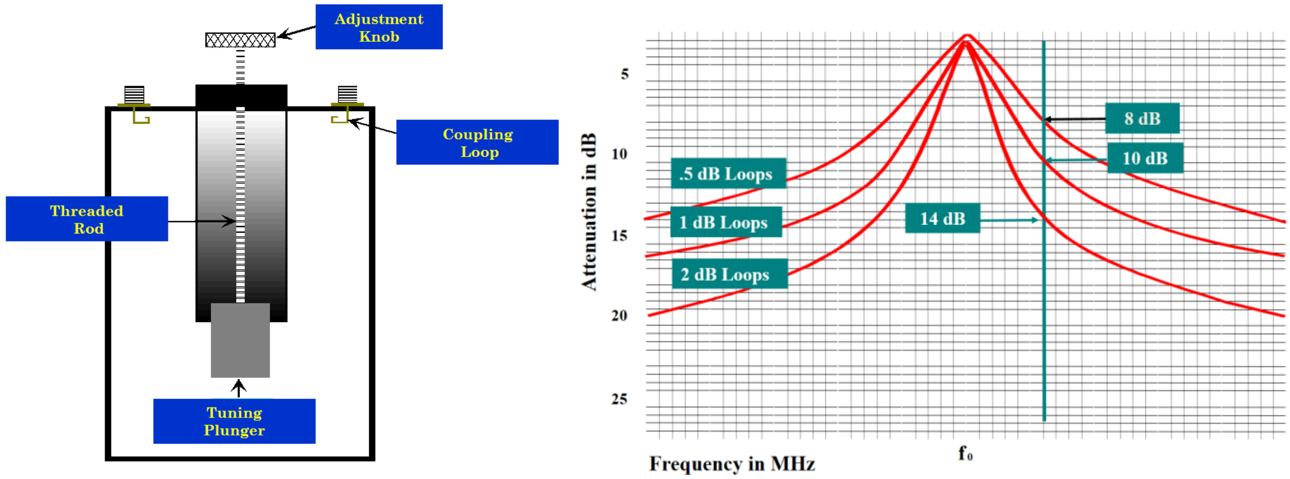


Figure 3: Selectivity vs. Q of cavity

Most cavity filters have adjustable loops. Adjusting the loops allows the Q of the cavity to be increased or decreased as needed. When the Q is increased with the loop, the Q is said to be electrically adjusted. Increasing the electrical Q of a cavity comes with an increase in insertion loss. ***Figure 3*** demonstrates how adjusting the loops for improved selectivity increases the insertion loss.

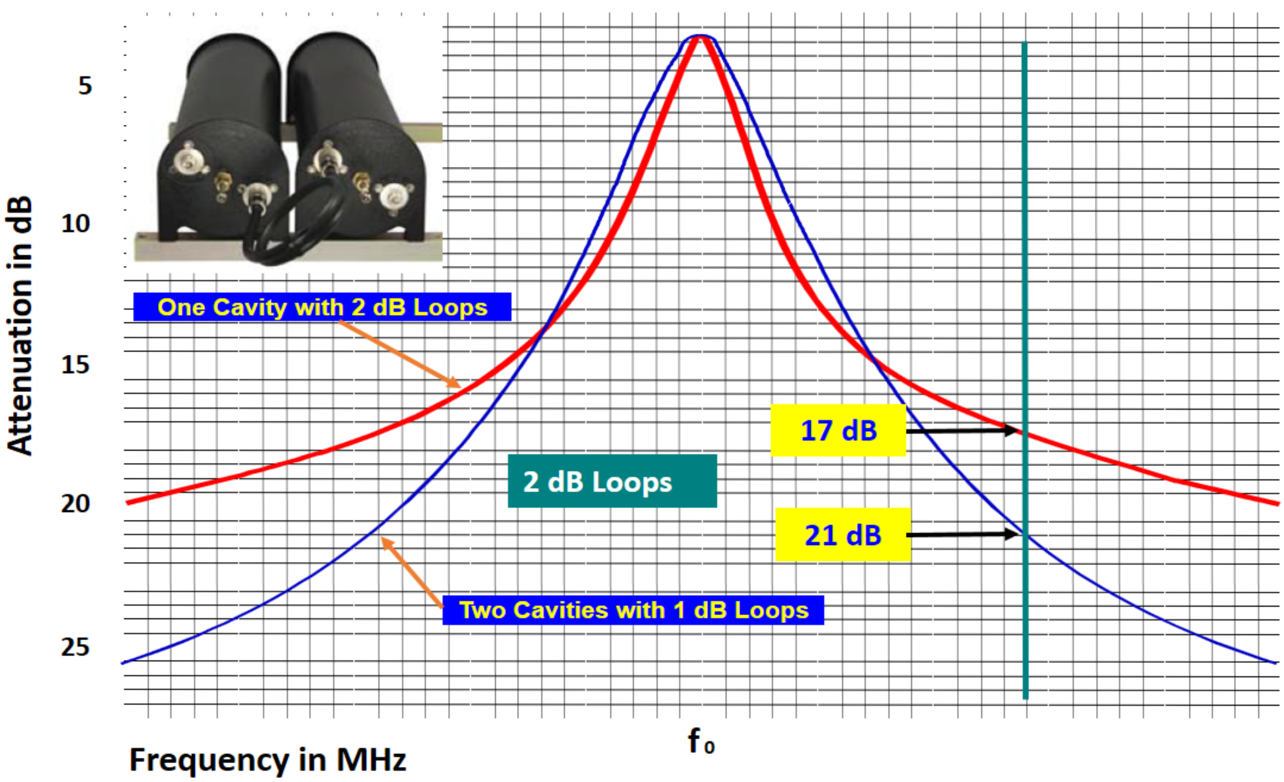


Figure 4: Multiple cavities to obtain improved selectivity

Cascading filters can improve selectivity without the penalty of greater insertion loss. Coupling multiple filters is more efficient than trying to obtain increased selectivity in a single cavity. ***Figure 4*** shows that using two cavities with 1 dB loops each will provide over 21 dB of selectivity where trying to use only one cavity with 2 dB loops only delivers 17 dB of selectivity. An additional benefit in using multiple cavities is the depth of the selectivity far away from the center frequency. While the typical selectivity depth of a single filter is less than 30 dB, the depth of two cavities (with equal Q) increases to about 60 dB.

Another way to increase the Q of a cavity is to increase the volume or physical size of the cavity. This is called changing the mechanical Q. The mechanical Q is a design change not an adjustment. Larger cavities will allow improved selectivity while not significantly increasing the insertion loss. In most cases the depth of the selectivity will not change with a larger cavity. For example, dbSpectra offers VHF cavities with eight inch and five inch diameters.

Notch Cavity ***(Figure 5)*** – The band-reject cavity filter, or notch filter, is a high Q resonant circuit designed to attenuate a narrow band of frequencies while allowing all other frequencies to pass through with only slight attenuation. The notch filter can be considered the opposite of the band pass filter. Energy at the resonant frequencies, or center of the notch, enters the cavity and is reflected back, out of phase with the original. This creates a virtual short across the transmission line and results in a high percentage of the applied energy, at the resonate frequency, being reflected back toward the source.

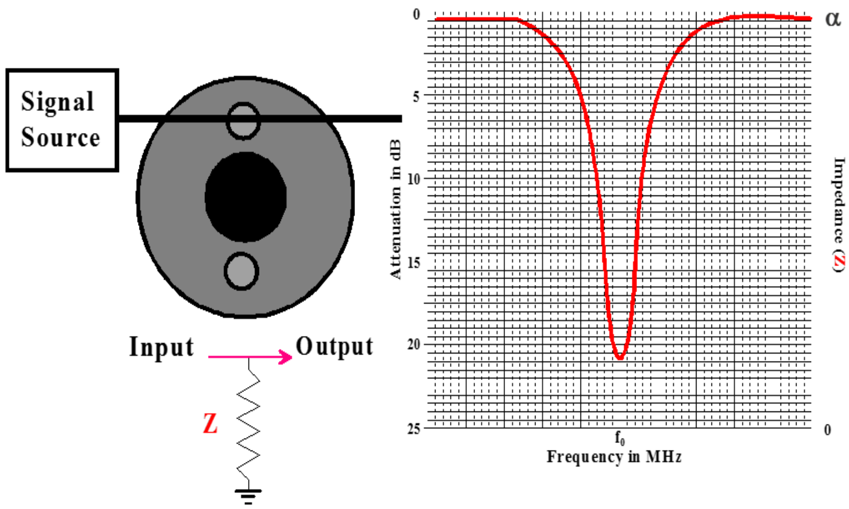


***Figure 5:** Notch Filter characteristic*

Maximum attenuation occurs at the center (resonant) frequency while all others are attenuated to a lesser degree depending on their distance from the center frequency. At the resonant frequency, the filter has a very low impedance approaching 0 Ohms. This effectively creates a short across the line. A small amount of the energy is absorbed into the cavity and dissipated but most of the energy is reflected back to the source due to the impedance mismatch created by the near short frequency. It is very important to understand that a notch filter only provides attenuation at one frequency or one small band of frequencies. Above or below the center frequency or bandpass the filter looks like a high impedance and provides no attenuation.

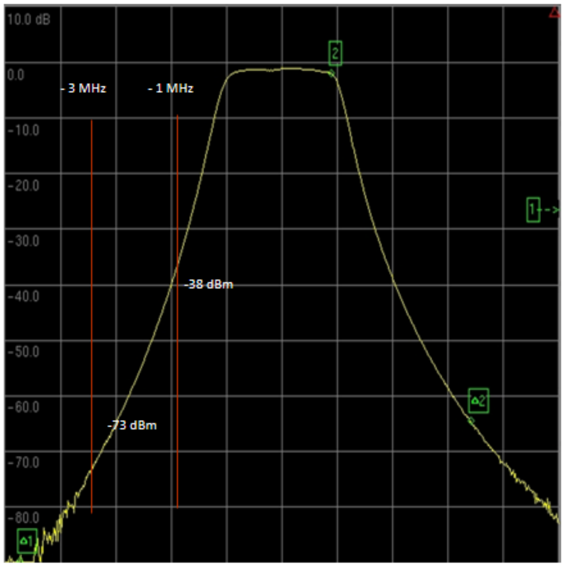
The spacing between the desired frequency and the frequency to be notched or rejected can be a few megahertz or 100 KHz or less depending upon the cavity's Q. If the attenuation or slope of the selectivity obtained is not adequate, several notch filters can be cascaded to improve the depth and slope of the notch.

Pass-Reject Cavity – Another useful cavity type is the pass-reject type cavity that is capable of providing both pass and reject filter characteristics. The trade-off is that both the reject or notch depth and the bandpass response are not as pronounced as pure reject or pass type cavities.

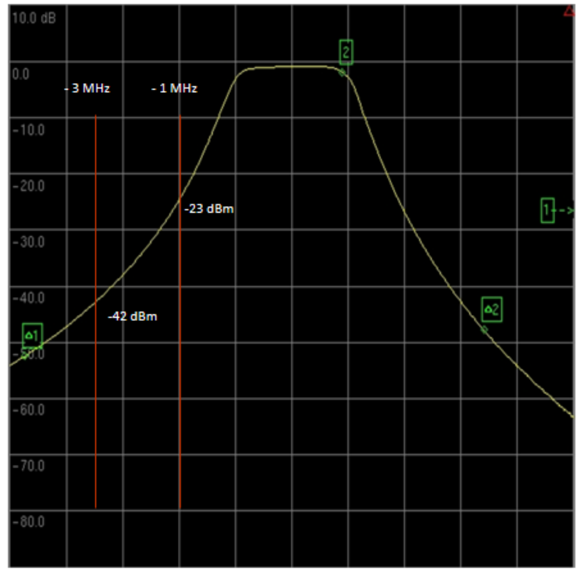
Milled Filter Technology – The most significant advancement in filter technology over the past 30 years is the milled filter. ***Figure 6*** shows example Milled filters used for various applications. Milled filters get their name from the way they are constructed. Instead of individual cavities being phased together, the milled filter is computer designed from a block of aluminum which is milled out to create the housing with multiple internal cavities. Milled filters are much smaller in size, have lower insertion loss for a given selectivity, and deliver significantly more selectivity depth. The biggest disadvantage of a milled filter is that it cannot be tuned in the field.

Figure 6: ***Milled Filter applications***

As more radios are being collocated the filter requirements have increased to allow the radios to operate without interference. ***Figure 7*** shows a comparison between milled filter performance and standard cavity configurations. Where a cavity provides only 25 – 30 dB of selectivity depth, the milled filter selectivity continues to increase as the off-frequency increases. The depth of selectivity can approach 100 dB far away from the center frequency. It is very important to note that a milled filter cannot be field tuned. dbSpectra has led the industry in development of milled filters and offers milled filters in all bands and various applications.



New Milled Filter



Multi Cavity Preselector

***Figure 7:* Milled Filter vs. Standard Cavity performance curves**

Not only do milled filters provided advantages compared with cavity bandpass filters but also compared with legacy filters. ***Figure 8*** and ***Figure 9*** show a comparison of legacy filters compared with a milled filter design.

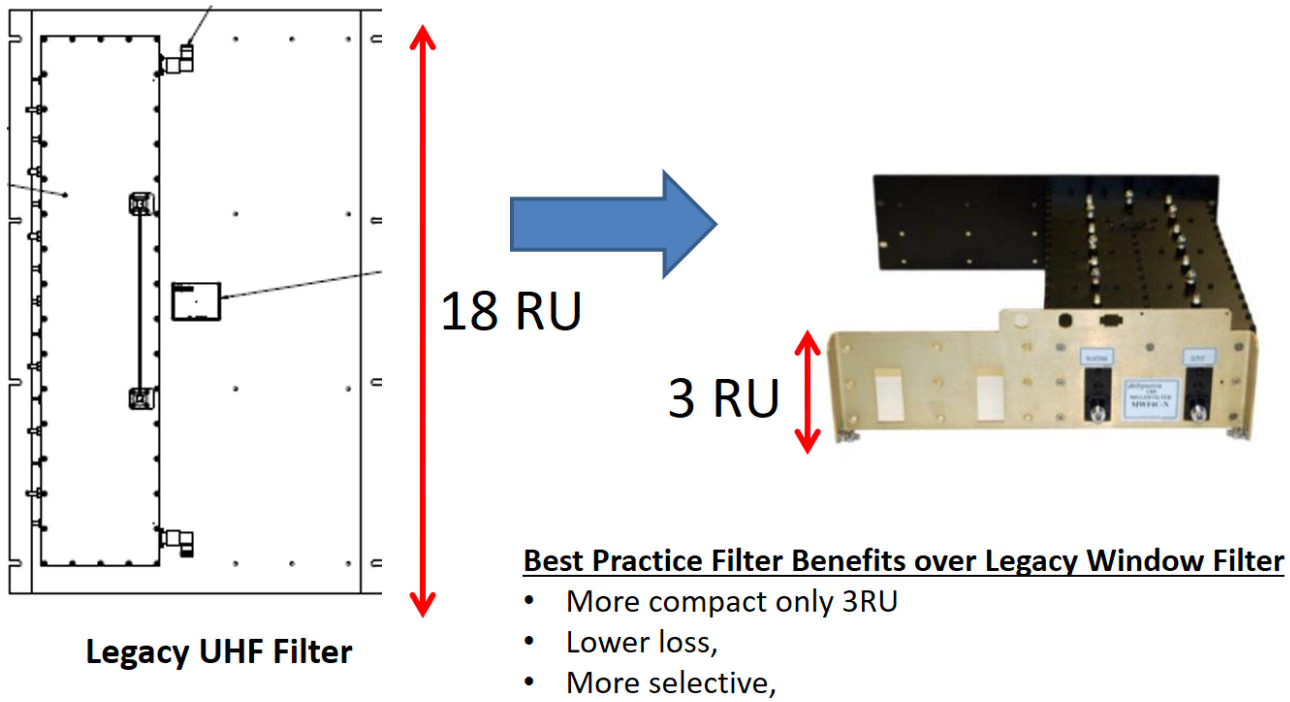


Figure 8: Bandpass milled filter compared with Legacy filter

Figure 9: Bandpass Duplexer response compared with Legacy filter response

Appendix D - Power Flux Density and Power at Antenna Terminal

Power Flux Density (PFD) at ground level is the preferred metric for a harm claim threshold because it translates directly to power captured by the public safety receiver while Power Spectral Density (PSD) and ERP limits can create strong or weak power flux density on the ground depending on antenna height, topography and antenna elevation pattern. FCC precedent for 700 MHz and 800 MHz operation establishes a PFD limit of 3,000 $\mu W/m^2$.[1] Our bench measurements of typical 900 MHz radios are based on power at the antenna terminal, not PFD, so a translation between PFD and power at the antenna terminal is needed. Assuming far-field plane wave propagation, a power flux density of 3,000 $\mu W/m^2$ is equivalent to an electric field strength of $E = 1.06$ V/m (found by applying Ohm's law and assuming free space impedance of 120π). Ignoring body loss for now, the gain of a half-wave monopole on a typical portable radio is $G = 0$ dBd or 2.15 dBi (1.64 ratio). The antenna factor is given by

$$AF = \frac{9.73}{\lambda\sqrt{G}}$$

where λ is the radio carrier wavelength in meters (0.35 m @ 851 MHz) and G is the antenna gain (ratio). For our example, $AF = 21.7\ m^{-1}$ and the voltage at the antenna terminals is E/AF or 0.049 volts. Assuming a 50 Ohm receiver, the corresponding receive power at the antenna terminal for a PFD of 3,000 $\mu W/m^2$ is -13.2 dBm. If a PFD per MHz standard is adopted at 900 MHz, the maximum power at the antenna terminal would be 5 dB (factor of 3) stronger, or -8.2 dBm.

[1] Actually, the standard in § 22.913 is PFD per MHz, but the receiver reacts to total power more so than power density, so we prefer a purely PFD limit on a per sector basis. See Pericle's filing in the WT Docket 12-40 proceeding, December 4, 2015.